Working Paper 3: Barriers, Incentives and Indicators

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BARRIERS, INCENTIVES, INDICATORS

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CC Transitions is an 18-months desk study funded under the Environmental Protection Agency (Ireland) Climate Research Call 2014 (Ref: 2014-CCRP-DS.6). The project will develop an analytical framework for understanding energy transition in Ireland, which will help frame future EPA research in this area. The research will review existing work on transition management, examine a number of international case studies of energy transition and map the state of transition of specific technological sectors in Ireland. The overall aim is to benchmark Ireland's progress to a low carbon economy, identifying future research areas to support this aim.

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Definitions and Acronyms

BEV	Battery-electric vehicle
CHP	Combined Heat and Power
DH	District Heating
Dispatchable Generation	Methods of on-demand electricity generation where electricity can be generated without long start-up/close-down processes.
Energiewende	The German energy transition
EEG	German Renewable Energies act
EPA	Environmental Protection Agency (Ireland)
EV	Electric vehicle
HEV	Hybrid electric vehicle
ICE	Internal Combustion Engine
IEA	International Energy Association
NEVA	Norwegian Electric Vehicle Association
OECD	Organisation for Economic Co-operation and Development
PHEV	Plug-in hybrid electric vehicle
SEAI	Sustainable Energy Authority of Ireland
STS	Science and Technology Studies
STUB	Early programme - Cooperation for Technological
	Development of Biogas Plants - in Denmark (1978-1986)

Executive Summary

The aim of the CCTransitions project is to attempt to benchmark the current state of the Irish low carbon transition against other countries and to better understand the ways in which such transitions can be conceptualised and operationalised.

This third Working Paper explores the drivers of transition by examining barriers and incentives to the adoption of renewable technologies, through examining technology case studies in bioenergy and electric vehicles. These are used to identify potential indicators for use in benchmarking the state of development of these technologies in the context of a broader sustainability transition in Ireland.

A Technological Innovation Systems (TIS) approach is used to categorise barriers and incentives in each case using the main functions identified in TIS research: knowledge development, knowledge diffusion, entrepreneurial experimentation, market formation, resource mobilisation, guidance of search, and the creation of legitimacy (Hekkert and Negro, 2011). These are accompanied by a discussion in each case of the broader context of technological development, and how the technology has developed in different national settings.

We have taken three case studies to examine these factors in more detail.

In terms of bioenergy, the focus here is on biogas production from farm waste using anaerobic digestion and the development of this technology in Denmark, the Netherlands and Germany is examined. Here we find different set of drivers: in Danish successes, experimentation, strong 'niche' networks and knowledge diffusion, supported by effective policy were instrumental; in Germany a strong transition vision and a robust series of policy instruments were effective. In both of these cases, the fact that biogas production also offered a solution to the problem of farm waste was also a strong incentive for developers.

The second case examines the growth of biofuels in Sweden, where government and car companies worked with actors in forestry and agriculture in a series of experiments to develop alternative fuels (mainly methanol and ethanol). What is interesting about the Swedish case was the effectiveness of using a mix of policy measures (both incentives and regulations) to ensure an adequate infrastructure to enable the diffusion of the technology. What this also demonstrates is the danger of "locking in" to a particular technology, where (possibly) unintended side effects (such as land use issues) arise. As registration figures show, the registration of ethanol vehicles in Sweden peaked and dropped possibly in response to this, with another factor here possibly being the drop in the price of crude oil. This underlines the importance of monitoring and reflecting on policy as broader contexts change.

The third case examined electric vehicles, and in particular examined the Norwegian case, which illustrated the benefits of matching supports with the level of development of the technology. This case also illustrated the importance of an advocacy organisation to disseminate knowledge and allow potential users to test-drive cars. One possible (unintended) side effect of the growth of EVs in Norway is an increase on overall car ownership, EVs tending to be adopted as a household's second vehicle for shorter journeys. This highlights the risk that car use might replace other alternative modes of transport such as walking, cycling or the use of public transport, and thus hamper a truly sustainable mobility transition. As EVs are only as sustainable as the electricity supply they use, and

there are still unresolved questions about the ultimate sustainability of battery technologies, it is important that the development of the EV innovation in particular settings is monitored in the context of their contribution to the overall mobility transition.

These cases contribute to the development of a evaluative framework to be used in the next phase of CCTransitions in assessing Irish technology case studies in Working Paper 4. Based on the Technological Innovation System and Transitions approaches, this will map the TIS of particular technologies within their overall societal context. Drawing from the cases discussed in this paper, Section 6 examines in more detail key areas for consideration when evaluating the potential of technologies to contribute to a society-wide sustainability transition. Three areas for particular investigation were identified as important to consider in the Irish case studies:

- Technology: technological readiness level and sustainability, including suitable indicators.
- Context of use: extent of learning networks; changes in social practice; and social acceptance including the extent of stakeholder involvement and level of participation in development and planning processes.
- Policy learning: policy coherence and integration- existing capacity and how to build in reflexivity in policymaking processes at different levels.

1. Introduction

Drawing from the theoretical framework introduced in Working Paper 1 of CCTransitions, and building on the national case studies discussed in Working Paper 2, this Working Paper aims to examine barriers and incentives to the adoption of renewable technologies by examining technology case studies on areas of bioenergy (notably biogas and biofuels) and electric vehicles. It will use these studies to identify potential indicators for use in benchmarking the state of development of these technologies in the context of a broader sustainability transition in Ireland (to be addressed in Working Paper 5). Technologies for the study were chosen for their particular relevance and potential for the broader processes of transition in the Irish context, and will provide a basis for the Irish case studies to be presented in Working Paper 4. Bioenergy was chosen for its ability to contribute to broader problems such as waste (in particular agricultural waste), and through its potential to provide a dispatchable energy source[1], which could act as a backup to the already existing wind capacity. Biofuels and electric vehicles both can contribute to lowering transport emissions, which comprised 19% percentage of Irish GHG emissions (EPA 2013), and 43% of Ireland's total energy use in 2014 (SEAI 2015).

1.2. Summary of Methodology and Paper Outline

A systematic literature review on these technologies was conducted, primarily focusing on papers adopting socio-technical transition or Technological Innovation Systems (TIS) approaches. Papers were reviewed for relevance and a number of other sources including 'grey' literature, were also added. Based on this literature review, the technological case studies presented in this paper are structured using a framework derived from and building on the technological innovation systems approach, oriented towards identifying barriers to and incentives for innovation. To address the limitations inherent in this approach, this framework has been augmented with insights from transitions theories (and other relevant work, see Working Paper 1), to enable the inclusion of contextual issues important to a broader societal transition.

The working paper first discusses the relationships between transition theories (STS, see working paper 1) and that of Technological Innovation Systems (TIS) and then introduces a series of technological case studies. For each case, following an introductory description of the technological area, a narrative account will be given of its development, drawing from TIS, STS and other relevant literature. Through this, incentives and barriers to the development and adoption of these technologies are identified, including technological, social, economic, behavioural, infrastructural and institutional factors. Following these case studies, there is a discussion of factors which need to be considered in adopting particular technologies to contribute to a low carbon energy transition in Ireland, based on the experiences within other countries, and highlights potential indicators.

[1] Dispatchable energy sources are those where power can be generated on demand (e.g. natural gas, biogas, hydro with pumped storage): i.e. plants do not require long starting up and closing down processes (e.g. coal, nuclear) or rely on an intermittent renewable source (e.g. sun, wind).

2. Structuring the Case Studies : Theoretical Frame for Analysis

The framework to structure the technology case studies draws on technological innovation systems and transition studies literatures.

2.1 Technological Innovation Systems (TIS)

The focus of analysis in the TIS approach is the 'innovation system'[2] surrounding a particular technology or set of technologies. Examination is made of the micro-dynamics of interactions between firms, universities, networks of entrepreneurs, value chains, and markets, and how these can be shaped in different ways by institutions and policies (Weber and Rohracher 2012). The approach can thus be used to provide a more detailed *diagnosis* of the current state of a technological innovation system through identifying barriers to innovation (see Working Paper 1) and in enabling the identification of targeted policy interventions (e.g. see Bergek et al., 2008; Wiezcorek et al., 2012). It therefore can provides a detailed template for data gathering, and as such will be a useful aid in structuring the Irish case studies to be conducted and reported in Paper 4. Steps in a TIS analysis may typically include:

1. A clear and explicit identification and communication of the analytic focus, (Bergek et al., 2008);
2. A description of **structural components** of the TIS such as actors, institutions, interactions and infrastructures (Wieczorek and Hekkert 2012) These are illustrated in Table 2.1 below.
3. An identification of key processes (**functions**) to provide an "achieved functional pattern" (e.g. Bergek et al., 2008). These are illustrated in Table 2.2 below. Particular structural elements might be linked with a number of these processes.
4. An evaluation of how well these functions are fulfilled, and the contribution of structures to this. Barriers and drivers towards the achievement of that function might be elicited.
5. A diagnosis of *systemic problems or failures* of different types, enabling the identification of areas where action, such as policy interventions, can be taken.

Systemic problems or "failures", can be diagnosed through examining the effectiveness of the structural dimensions involved in each process (Wieczorek and Hekkert 2012). For example, there may be barriers to market formation due to problems with infrastructure, cost to users, user perceptions, or technical problems. Technical problems in turn may have arisen through inadequate capacity for knowledge development or diffusion between relevant parties or a lack of entrepreneurial actors. Costs or uncertainties regarding the supply chain may be a barrier to the existence of entrepreneurial actors. These diagnoses can inform the prescription of specific policy instruments to remedy gaps in capacity. Table 2.1 illustrates structural elements and some of the diagnostic questions that could be asked in each area(ibid).

Structural Dimensions/ Diagnostic questions	**Description**

[2] Science and technology policies, in many countries (including Ireland) rely strongly on innovation systems approaches, such as those advocated by the OECD. Innovation policies (and innovation systems approaches) tend to focus on **micro-dynamics** of the interactions between firms, universities, networks of entrepreneurs, value chains, and markets, and how these can be shaped in different ways by institutions and policies.

Actors: Who are the actors and what are their capabilities?	• Civil society • Knowledge institutes • Companies • Government • NGOs • Other parties e.g. legal, financial etc. • *How well are these actors networked (formal and informal arrangements) ?*
Institutions: Are these sufficient? Do they act as incentives or barriers?	• Hard: rules, laws, regulations • Soft: customs, habits, practices, values, worldviews, norms, expectations
Infrastructures: Do these exist where needed and are they effective?	• Physical • Knowledge/informational • Financial
Interactions : Do sufficient (intensity and quality) interactions of adequate quality take place between relevant actors?	Communications between individuals and groups (can be too low, or too high- e.g. groupthink), Nature of networks (homogenous, heterogenous).

Table 2.1: Diagnosing systemic problems through examining the adequacy of actors, institutions, infrastructures and interactions involved in each of these processes (adapted from Wieczorek and Hekkert 2012).

1. **Entrepreneurial experimentation**: importance of active entrepreneurs to generate new opportunities, foster learning
2. **Knowledge development**: R&D, knowledge gaps, learning of different types
3. **Knowledge diffusion:** communication amongst heterogenous networks, fora, media
4. **Guidance of the search**: setting parameters for selection e.g. expectations, policy targets
5. **Market formation:** overcoming market costs to users, providing infrastructure etc.
6. **Resources mobilisation**: finance to drive other functions, human resources, etc.
7. **Creation of Legitimacy**: advocacy coalitions, counteracting resistance of different types etc.

Table 2.2 Key Processes in TIS Analysis (adapted from Hekkert and Negro, 2011)

In the context of this study, a TIS perspective has a number of weaknesses, such as the fact that it does not have an overt 'sustainability' focus but emphasises innovation and markets for any proposed technological solution. It also does not adequately consider technologies in their broader contexts of use, including some social acceptance issues. It also does not address the emergence of unintended side effects of technology diffusion, policy mechanisms to incentivise this, or the particular role that a technology might play in a society-wide transition. These limitations will be addressed through the incorporation of additional criteria into our analysis, drawn from strands of transition theory, and other relevant approaches.

2.2. The Transitions Approach

The transition studies perspective considers technologies in the context of larger scale processes of transition and helps identify areas of "lock-in" which inhibit required change. In contrast to the TIS approach, which focuses on technology-specific systemic change, it provides a longer-term view on the more strategic transformation of broader systems of production and consumption (Weber and Rohracher 2012), and is thus a valuable complementary approach. As discussed in Working Paper 1, socio-technical **regimes** comprise the dominant structures (including legislation, standards), cultures (include deeply entrenched worldviews) and practices (including habits) of particular societal systems such as the energy system (currently dominated by fossil fuels) or particular elements thereof. Innovative (here more sustainable) technologies or social practices arise in protected spaces or '**niches**', which challenge and may ultimately displace or transform incumbent **regimes** over longer time periods. External (**landscape**) catastrophic events such as resource shortages or weather crises might be instrumental in catalysing the rapid development and diffusion of particular technologies or social practices. Slower, more transformational regime change may occur through response to factors such as increased societal awareness of ecological problems, or through legislative requirements, such as those resulting from climate agreements. Related regimes may also be relevant to examine; for example, in the development of bioenergy and electric mobility, these include the following:

1. **Electricity regime**: These include existing physical infrastructures for electricity generation and distribution, which are centralised and rely largely on fossil fuels; billing systems; regulations governing the production and distribution of electricity; social practices reliant on the current model of electricity provision; culture within the industry etc.
2. **Transport regime** : Legislation(taxes, regulations etc.), infrastructures, (fuel distribution networks, road infrastructures) and markets oriented towards the usage of (petro-chemically fuelled Internal Combustion Engine -ICE) private cars.
3. **Heating (cooling) regime:** individualised home heating systems based on oil and coal, social practices such as daily showering which rely on hot water(Shove and Walker 2010).
4. **Agriculture regime** may act as a source for bio-energy feedstocks, may use biogas for heating.
5. **Waste regime** may act as a source for bio-energy feedstocks.

Transitions analyses indicate where path dependencies emanating from sunk costs in infrastructure or habitual or 'locked-in' practices could be addressed, for example through the provision of new or modified infrastructures such as smart grids, re-charging networks for electric vehicles or incentivising, facilitating or educating for behavioural change. More subtle barriers, for example dominant knowledge paradigms, might also shape the search for solutions in particular ways, and this may make it difficult for 'niche' technologies or practices to gain purchase[3]. The analysis of niche dynamics (Smith and Raven 2012) enables identification of which regime dimensions lead to the need for niche *protection* and how this might be provided through actions taken to shield, nurture or empower particular social or socio-technical innovations. Approaches such as strategic niche management stress the role of envisioning, network formation and learning in this. Examining niche dynamics also provides a rich source of information regarding what might be blocking desired change at the niche level. Analyses thus provide longer term perspectives on the introduction of 'niche' sustainable technologies in particular national settings, characterised by a systemic multi-level evaluation of the evolution and interaction of processes including learning, envisioning and networking.

[3] One example is the way in which energy production technologies could be viewed as providing solutions to problems, in a manner which ignores broader aspects of change in consumptive practices that could be required.

In an early stage of transition, there are steep learning curves and many diverse niches, which could potentially grow, link up and become the basis for new regimes. Whilst these processes of learning are on-going, it is important to avoid 'locking in' to any particular approach, as unintended side effects which could become new persistent problems might emerge. Box 1 discusses in more detail how this happened with biofuels. The biofuels example underlines the need for broader, more reflexive policy development and monitoring to consider the *sustainability* of particular approaches (which may be subject to contestation and may not be clear at the outset), and the danger of unintended side effects emerging from any technological solution or policy. Where particular policy instruments are used to provide protection for niche technologies, it may also be important to examine the interaction of these with policy or activities in other regimes; as acknowledged in Paper 2, interlocking regimes such as agriculture, transport, waste or housing may have contradictory or *incoherent* policies or regulations. For instance, barriers to the use of biofuels may arise through poor availability of feedstock sources (due to, for example, a poorly co-ordinated waste regime), environmental regulations, or adverse public opinion. Policy measures can prove to be ineffective or too costly- for example grant uptake may be too low (so ineffective) or too rapid (so too costly). Problems may also arise where inconsistent or fluctuating policies measures lead to longer-term uncertainty. Other important factors include social acceptance issues, as the cases of wind energy and grid expansion in Ireland have clearly illustrated (NESC 2014a, b).

Box 1. How Bio are Biofuels?

The issue of the rapidly evolving evidence base for the sustainability of Biofuels provides a useful illustration of the complex relationship between policy making, learning, indicators and the research evidence base. The promotion of biofuel production by policy makers was based on the assumption that that substituting biofuels for diesel in road transport would reduce greenhouse gas emissions (relative to fossil fuel use) because biofuels sequester carbon when the feedstock is grown.

However, In common with all industrial processes, production of biofuels requires energy inputs and this is further complicated by issues related to feedstock production (agriculture) and land-use change (for example, the conversion of a greenhouse gas sink such as forest, to cropland).

Life cycle analysis (LCA) is the methodology used to quantify the whole life-cycle environmental costs and benefits of products and processes, and underpins energy and resource management policy in the European Union (Union, 2003). It is also the methodological basis for the Carbon Footprint of products and processes (Eurpean Joint Research Centre 2007).

The earliest research which quantified the full life-cycle greenhouse gas (GHG) emissions from biofuel production (including land use change) used a worldwide agricultural model to estimate emissions from land-use change and concluded that biofuel production from corn and switchgrass both resulted in increases in GHG emissions, relative to fossil fuels (Searchinger et al., 2008).

This debate has been focussed around the issue of 'estimated indirect land-use change' (EILUC). While subject to high levels of uncertainty, the evidence showing that greenhouse gas emissions associated with biofuel production (when the effects of EILUC are included), indicating that 'Greenhouse Gas Emissions (GHGs) from biofuels [] may be much greater than previously estimated', has continued to build (Plevin, O'Hare, Jones, Torn, & Gibbs, 2010).

The high levels of uncertainty referred to above have highlighted the need for further Life Cycle-based research in this area and the need for policy to be flexible, with one author stating 'Due to the level of uncertainty, monitoring capacities (land use patterns) and research have to be improved and a regular "health check" of biofuel policies should be implemented' ((IFPRI), 2011). They also raise the need for an effective science-policy interface, and reflexive governance mechanisms where policy can adapt and respond in the light of emerging evidence.

2.3 Social Acceptance of Technologies

Wolsink et al (2012) argue that social acceptance is a key element of why the transformation of the energy supply and demand systems of developed countries into sustainable systems is poorly understood in policy realms. A major dimension of social acceptance is the recognition of all *consequences* of the innovation including the ways in which it will change social practices[4] (ibid). These problems may be ameliorated to a certain extent through participation by a wide group of stakeholders (including civil society) in development processes from an early stage, where learning, envisioning and knowledge dissemination become central processes. This can be seen in the success of the more participative and grassroots approach adopted in Denmark in developing farm-based biogas systems which will be discussed in Section 3 below. Here, the emphasis on on-going learning processes coupled with incremental development, implementing what was learnt (as described by Raven and Geels 2010) proved to be important.

Wolsink also raises the need to consider spatial issues, arguing that for projects in particular locations, it is not only necessary to examine technological elements and willingness of a variety of actors to invest in the technology, but also the *settings* in which implementation will take place. Here issues of ownership and trust arise, and these are (again) influenced by the level of stakeholder involvement (including meaningful deliberation) in planning and managing aspects of the design and implementation of the technology. Wolsink et al note that factors such as the emotional and cultural relationship between people and location play a highly significant part in degree of acceptance in addition to economic factors (ibid). The fact that these have hitherto been ill-considered by policymakers in Ireland has resulted in poor acceptance of certain technologies, notably wind, as discussed by NESC (2014).

The above examples raise the need to assess how stakeholder views (including those of affected members of civil society) and reflexivity can be incorporated into the design, development, or diffusion processes of renewable technologies and the policy-making processes governing these. They also underline the need to view the transition to a sustainable society as a holistic and systemic process. This means that any particular technology needs to be considered with respect to the role played in the larger system and in the context of use. For example there are major differences between industrial scale wind-farms installed by private investors on public land with limited input from affected residents and smaller community-owned projects which use smaller wind installations as an adjunct to other technologies and practices for energy production or energy saving. Both of these approaches come with different and diverse sets of challenges regarding costs, social learning and grid technologies (see, for example NESC 2014a, b). They also both embody different sets of values and illustrate the importance of ensuring that processes of learning (both technical and social) are embedded at all levels, to avoid the danger of lock-in to a less sustainable, or technically/socially unfeasible path.

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[4] This can be seen to work in ways in ways more or less desirable from either user or broader sustainability perspectives. For instance, in the case of Norwegian EVs above, where second car use increased, new social practices (and possibly dependencies) developed, which were arguably less desirable from a sustainability perspective, but maybe more comfortable from a user's perspective.

2.4 Hybrid Approaches

There have been a number of attempts to combine TIS and transitions approaches, harnessing the strengths of each. These have different aims: Weber and Rohracher (2012) extend the analysis of innovation system failures with the aim of providing a comprehensive framework to devise and legitimise policies for transformative change. Markard et al (2009) combine TIS and transitions approaches with scenario development to enable the comparative analysis of development options within a chosen innovation field, hence adding a futures dimension to analysis. To assess the overall "transformation potential" of a technological innovation system, Weber and Rohracher (2012) integrate aspects of the transitions perspective with the 'failures' approach to designing policy to improve innovation systems. To this end, they add a new category of systematic failures - 'transformational failures' – to incorporate considerations necessary when designing policy to catalyse a broader societal sustainability transition. This addresses issues such as:

1. Directionality – the overall direction of change (i.e. how *sustainable* is the direction), the need for a shared vision;
2. Demand Articulation- anticipating and learning about user needs;
3. Co-ordination - horizontal - the need for policy integration/coherence between different sectors; and vertical – global/EU/national policy integration/coherence;
4. Reflexivity – the ability of the system to monitor, anticipate and involve actors in processes of self-governance.

Table 2.3 provides a summarised and edited version of their overview of the systemic failures framework.

A more fine-grained, futures perspective to a TIS analysis is provided by Markard et al (2009). Here, the context for choices of technological paths and the factors governing the emergence of possible future scenarios within a specific innovation field are examined in conjunction with a range of development options. Scenarios are constructed through the identification and analysis of "coherent technological variants and actor constellations" (ibid: 655) with attendant institutional structures which might form the basis of future developments in a TIS. Their analysis is based on the idea that any given technological innovation system (anaerobic biogas digestion in the case examined) is embedded in a context that may support or constrain its development potential. The multi-level perspective (MLP) is used to describe this context, which is viewed as consisting of established regimes, a broader landscape and other competing or complementary 'niche' TIS. The addition of foresight and scenario methods enables the examination of combinations of factors which might trigger the unfolding of particular development paths[5].

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[5] The main steps include:

(i) a **basic analysis** of the TIS, with a focus on : innovation characteristics (technical and market); actors and networks; institutions(such as specific R&D programs, regulations, expectations, norms and values that influence the innovation field); lessons from other countries;

(ii) a **context analysis** which includes relevant regimes, landscape level factors and competing and complementary innovation systems (niches); and

(iii) a **variation analysis** – a systematic search for current and potential configurations in socio-technical and organisational terms, providing a spectrum of alternative development options that have a certain degree of coherence along different dimensions. (Markard et al 2009)

Failure Type	Failure Mechanism
Market (need for state investment)	Uncertainty about outcomes and short time horizon of private investors lead to undersupply of funding for R&D.
	Socially sub-optimal investment in (basic) research and development.
	Possibility to externalize costs leads to environmentally or socially damaging innovations.
	Public resources over-used in the absence of institutional rules that limit their exploitation (tragedy of the commons).
Structural	**Infrastructural:** Lack of physical and knowledge infrastructures due to large scale, long time horizon of operation and too low return on investment.
	Institutional: Hard: Absence, excess or shortcomings of formal institutions such as laws, regulations, and standards; Soft: Informal institutions (e.g. social norms and values, culture, entrepreneurial spirit, trust, risk-taking) that hinder innovation.
	Interaction: **Strong network failure**: Intensive cooperation in closely tied networks leads to lock-in into established trajectories and a lack of infusion of new ideas, due to too inward-looking behaviour, lack of weak ties to third actors and dependence on dominant partners. **Weak network failure**: too limited interaction and knowledge exchange with other actors inhibits exploitation of complementary sources of knowledge and processes of interactive learning.
	Capabilities: Lack of appropriate competencies and resources at actor and firm level prevent the access to new knowledge, and lead to an inability to adapt to changing circumstances, to open up novel opportunities, and to switch from an old to a new technological trajectory.
Transforma tion	**Directionality:** Lack of shared vision regarding the goal and direction of the transformation process; Inability of collective coordination of distributed agents involved in shaping systemic change; Insufficient regulation or standards to guide and consolidate the direction of change; Lack of targeted funding for research, development and demonstration projects and infrastructures to establish corridors of acceptable development paths.
	Demand articulation: Insufficient spaces for anticipating and learning about user needs to enable the uptake of innovations by users. Absence of orienting and stimulating signals from public demand Lack of demand-articulating competencies.
	Co-ordination: Lack of multi-level policy coordination across different systemic levels (e.g. regional–national–European or between technological and sectoral systems; Lack of horizontal coordination between research, technology and innovation policies on the one hand and sectoral policies (e.g. transport, energy, agriculture) on the other; Lack of vertical coordination between ministries and implementing agencies leads to a deviation between strategic intentions and operational implementation of policies; No coherence between public policies and private sector institutions; No temporal coordination resulting in mismatches related to the timing of interventions by different actors.
	Reflexivity: Insufficient ability of the system to monitor, anticipate and involve actors in processes of self-governance; Lack of distributed reflexive arrangements to connect different discursive spheres, provide spaces for experimentation and learning; No adaptive policy portfolios to keep options open and deal with uncertainty.

Table 2.3 Overview of System Failures in the Context of Transformative Change (adapted/summarised from Weber and Rohracher 2012: 1045).

An assessment of alternative development paths can then be conducted, for example on the basis of a systematic review of the factors that promote or hinder the emergence and diffusion of the variants identified. This approach is beneficial in that it combines a rigorous assessment of particular technological options with a contextual analysis of the factors which might drive and inhibit their development, and provides a useful practical tool that can be used to structure and ground scenario analyses.

2.5 Reflexivity, Research and Policy

One of the limitations of time constrained desk study research, such as this project, is that it is limited to using insights from these frameworks to inform a more *static* analysis, effectively providing a snapshot of the state of particular technologies in time (see Paper 4); however it is important at this point to examine the potential of these analyses for use in on-going policy learning processes. Weber and Rohracher (2012) explore how failures analyses, such as those described above could be used as a basis for reflexive policymaking processes, enabling policy co-ordination, user involvement and reflexivity to be incorporated. To this end, they suggest creating 'new interfaces' between existing innovation policy arenas and other types of policies or actors and including formal and informal discursive spheres. These arenas (not unlike 'transition arenas' discussed in Paper 1) can be viewed as "hybrid forums" which would serve as both coordination devices for sense-making and envisioning or as spaces for interaction, experimentation, monitoring and learning[6]. These could be backed up via a continuous monitoring and anticipation function, providing an evidence base to legitimise policy interventions. They envisage that this would take into account the distributed nature of decision-making and could involve an array of mechanisms such as formal stakeholder consultation, or commissions of inquiry. How such "hybrid forums" could be created in Ireland (or the extent to which they exist) would be a valuable area to explore when conducting case studies.

Markard et al (2009) describe a more fine-grained and structured approach to analysis, elements of which could be used to provide evidence for continuous policy monitoring and anticipation activities as envisaged by Weber and Rohracher. These analyse the development of different technological options; and can be combined with scenario planning approaches where alternative future trajectories can be envisioned and assessed. An important aspect of scenario planning methods, beyond envisioning is an on-going monitoring process to enable the type of trajectories emerging to be mapped. How particular types of 'hybrid forum' and monitoring activities could be set up to enable deliberation and debate on emerging technological trajectories, and how these could be informed with comprehensive information from a range of perspectives, enabling a more systemic (and effective) approach to technological innovation is an area which warrants more attention. This will be re-examined in Section 6, following the case studies.

[6] Learning here would include more reflexive or "higher order" learning where systems of operation (and assumptions governing analyses and decision-making) are reflected on and revised as appropriate.

Part 2 : Case Studies

The next sections describe a number of technology case studies, constructed from a review of literature using TIS and transition perspectives of the technologies in question (and other grey literature where appropriate). Incentives and barriers to the development of these technologies (as evidenced through the literature) are summarised using a frame based on the TIS approach (Weiczorek and Hekkert 2012). An assessment of the broader context for each technology in terms of landscape forces, relevant regimes and key niches (Markard et al 2008) is also given, and where appropriate, insights on 'transformation potential" (Weber and Rohracher 2012) are also incorporated.

One of the purposes of this approach has been to classify and characterise barriers in these cases (and how they were addressed) to enable an assessment of the types of issue that may require focus in a future analysis of Irish technologies, and help identify which potential indicators may be important. These have enabled the design of an assessment framework incorporating sets of diagnostic questions to determine the overall state of different functions or processes within particular technological innovation systems (illustrated in Appendix A) which will be used to conduct the Irish case studies in Paper 4.

To introduce the Case Studies, Box 2 provides an overview of bioenergy, to illustrate the complexity of the bioenergy system.

Box 2. Overview of Bioenergy

As the discussion in Box 1 indicated, Bioenergy is complex area, and has become a stark illustration of the need for comprehensive analysis of the sustainability of offered technological solutions. A wide diversity of energy sources and end-uses are involved, with different forms and scales of processing. As such, it incorporates a number of technological innovation systems.

One of the advantages of certain forms of bioenergy, according to Energiewende (2015), are that biomass not only can provide electricity, heat and fuel, but it is also easily storable and *dispatchable*. In other words, unlike solar, wind, or even nuclear sources of energy, a biomass plant can be started up or shut down on demand, thus making it a useful adjunct to other fuel sources. However the main drawback with bioenergy is that it needs careful management (and monitoring) to be sustainable (ibid). Particular forms of bioenergy have been the source of much controversy: as the discussion in Box 1 made clear, serious environmental and social problems have been associated with first generation biofuels. It is thus important to consider the sustainability of biomass over the entire lifecycle from a number of perspectives, such as the need for a constant supply of biomass and the sustainability of the sources (factoring in issues such as transportation or displacement of food sources).

Bio-energy production can also be highly dependent on other socio-technical systems, either to provide inputs (for example the agricultural system or the waste disposal system) or to utilise products (for example the transport system, the electricity production system, or systems for district heating). There also may be environmental impacts at different stages of the process: sources such as marine algae may raise issues of coastal management and environmental protection; the cultivation of energy crops might displace necessary food crops or reduce biodiversity; use of landfill sources may pose significant health risks. At a micro-level, community based systems such as Germany's "bioenergy villages" (Von Bock und Polach et al 2015) require trust and appropriate governance within communities.

It is important, therefore, to examine the use of particular sources of bioenergy in a more holistic way, such as using social-ecological or circular economy perspectives. There can be external benefits, such as the disposal of different forms of waste and the production of new resources using by-products. Factors that are important to examine include the scale of and context of production and the location/viablilty of feedstocks.

3. Case Study 1 : The Production of Biogas from Farm Waste

Biogas from farm waste is generally accepted as a relatively mature technology and is interesting for Ireland in the context of an overall "climate-smart agriculture" strategy (EU Agriculture 2015, IIEA 2015) where anaerobic digestion techniques can be used as part of an overall set of mechanisms to reduce agricultural GHG emissions. As agriculture is a major contributor to Irish GHG emissions[7], carbon neural agriculture is one of the five strategic building blocks recommended in the 2012 NESC report: "Connecting how much with how to" (NESC 2012). The biogas niche thus has particular relevance for transition in the agricultural regime, as it involves novel practices for dealing with waste, and provides a potential energy source which can be used for heating either at a local level or more generally depending on the location of processing (farm-based or central). As certain forms of waste can be used for co-digestion, it also has relevance for the waste regime. Gas can be used in heating systems and CHP plants, possibly as the basis for a community energy scheme (see e.g. Wirth 2014). Treated gas can also be used as a biofuel or distributed via existing gas infrastructures.

3.1 Description of the Technology

Development of this technology began in European countries as a response to the oil crisis in the 1970s. Anaerobic digestion of biogas uses animal manure as the main feedstock, and treated waste can be spread on land, with reduced pollution and odour. Following the pre-processing of manure to ensure homogeneity, a process of anaerobic digestion of this, with the addition of other organic waste such as fish oil (which would otherwise go to landfill), typically results in a mixture of (mostly) methane and carbon dioxide being produced, which needs cleaning to be used as an energy source. Gas produced can be used in combined heat and power plants (CHP), for district heating, or injected into a natural gas grid (Raven and Geels 2010, Smink et al 2015). Processed manure can also be used as a fertiliser or to produce fertiliser pellets. Gas can also be further refined for use as a biofuel (Huttunen et al 2014).

A number of factors have been instrumental in technological development and adoption Raven and Geels (2010) examine the development of two types of biogas plant in the Netherlands and Denmark using strategic niche management and social constructivist perspectives:

- farmscale plants which process manure for use on a single farm, and typically use the biogas for heat or power locally, and put the processed manure on the land;
- centralised plants take manure from a number of farms. They also may have additional functions such as the production of fertiliser pellets for market. Here, transport and storage are also issues.

Other studies have examined developments in Sweden (Olsson and Fallde 2015), Germany(Sutherland et al 2015, Poeschl et al 2010) and the Czech Republic (Sutherland et al 2015).

[7] "The agriculture sector accounted for 32.6% of Ireland's total national emissions in 2013 and this is amongst the highest of any country in the developed world."
[http://www.agriculture.gov.ie/ruralenvironment/climatechangebioenergybiodiversity/agricultureclimatechange/]

3.2 Contextual Analysis: Farm-Based Biogas Niches (in EU Countries)

As discussed in Paper 2, the oil crises of the 1970s and consequent rises in energy prices were major landscape forces which drove experimentation in alternative energy sources in a number of countries. In Denmark, these triggered a long (over 30 years) process of niche development, involving significant learning about the production of biogas from farm waste, beginning with farm scale plants, but also relating to more centralised plants (Raven and Gregerson 2007, Raven and Geels 2010). At an early stage, Raven and Geels note that the lack of an existing knowledge base was countered by the expectations of farmers, research centres, and new technology companies, backed up by a strong Danish grassroots movement. Key actors included the Danish grassroots movement[8], scientists, local energy offices, and farmers (ibid). In West Germany, biogas adopters were alternative (mainly organic) farmers, who addressed environmental concerns, and in Czechoslovakia, they were collective farm staff (including engineers) dealing with the large waste management issues resulting from collectivisation. The first biogas plant was established in Czechoslovakia (in Trebon) in 1974, but investment remained at farm level until the 1990s (Sutherland et al 2015). Experiments were also conducted in Sweden (Olsson and Fallde 2015).

At these early stages, 'niche shielding' (Smith and Raven 2012) was provided through different forms of grant aid which were instrumental in incentivising the experimentation and development of biogas technologies. For example, in Denmark in 1978, a small grant was provided by the Ministry of Trade to the new Cooperation for Technological Development of Biogas Plants (STUB), which used this to provide support to assist farm-scale plant construction. A range of experts were mobilized and seven plants were constructed to enable learning to occur on the technical and economic aspects of running biogas plants (Raven and Geels, 2010). In Sweden, farm-based biogas systems were subsidised and plants were built through collaboration between farmers and universities (Olssen and Fallde, 2015). Funding for research and development also enabled experiments where researchers and farmers collaborated in the Netherlands (Raven and Geels, 2010).

The results of these early experiments showed that, despite lessons learned, farm-scale plants were beset with technical problems and had limited economic benefit:

> Researchers and technology suppliers learned detailed lessons about manure composition, microbiological processes inside the digester, and relationships between temperatures, processing time, and biogas yields. They learned about technical components such as manure storage systems, manure pumps, gas engines, heat exchangers, cutters, mixers, and separation technologies. Several components proved to be vulnerable. The pump that supplied manure often suffered blockage. Devices to stir manure inside the digester worked insufficiently and often broke down. Furthermore, it was learnt that biogas contained small amounts of hydrogen sulphide, which damaged gas engines and transport pipes because of its corrosive properties. A major disappointment was that biogas yields, and thus savings on energy costs, were lower than estimated calculations, in some plants 50% below initial expectations. As a result, all plants had negative returns on investment. " (Raven and Geels 2010:93)

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[8] This included Folke High Schools, which provide opportunities for life-long learning, including the Nordic Folke Centre (http://www.folkecenter.net) formed to research into, develop and train in renewable energy technologies.

In Denmark, interest largely waned at this point; however the existence of a grassroots movement, and in particular organisations with strong commitment to renewable energy such as the Nordic FolkeCenter meant that it did not die out altogether. These technical difficulties in the Netherlands were initially framed as 'teething problems' which temporarily assuaged concerns, but eventually, in the absence of greater successes, the original networks weakened. In Sweden, a similar situation arose where plants were heavily dependent on government subsidies and were no longer economically viable when subsidies ceased. Olsson and Fallde (2015) suggest that as a social network had not become sufficiently established at this point, farm-based biogas production largely declined.

In Denmark and the Netherlands, Raven and Geels (2010) note that the negative lessons learnt from these earlier experiments shifted focus towards research into centralised biogas plants. In the Netherlands these were driven by the increased pressure from the EU to deal with farm waste (the EU Nitrates Directive 1991), and two large plants were constructed to digest waste and produce fertiliser for market. The first experienced significant technical difficulties, and there were problems with the stability of the fertiliser produced. There was also a clear disconnect between learning and decision making processes, where expansion occurred *despite* well articulated problems (Raven and Geels 2010). The second plant also experienced problems. However, when they sought to benefit from Danish and German learning processes and introduce co-digestion of landfill waste to improve production, opposition came from the local authority, who had invested in alternative arrangements for waste processing, and would not guarantee a supply of waste. Thus, through a combination of poor communication, questionable decision-making processes and path dependent processes (sunk costs) in the waste regime, both plants failed. Interest in biogas in the Netherlands thus waned, until developments in Germany and Denmark[9,10] coupled with the need to address climate change, re-ignited interest.

In Denmark it was considered that developing centralised production would shift responsibilities to professional firms and enable economies of scale. In addition, local authorities became interested due to the potential of biogas to feed district heating (DH) networks, which were at that stage mainly fed by gas and oil (Raven and Geels 2010). Three plants were constructed, largely funded by grants from the government, and in one case partly funded a local authority. Initial technical problems in one plant were addressed through reconstruction. Biogas yields at this stage were below expectations. Despite this, following the Government's rejection of nuclear power in 1985, interest increased in natural gas being used for local district heating systems and CHP units. In areas where a natural gas infrastructure did not exist, further support for the use of biomass (including biogas) was given. Alternative energy sources were also exempted from tax applied to fossil fuels. As in the Netherlands, changes in the agriculture regime forbidding the spreading of manure at certain

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[9] Co-digestion of other waste sources increased biogas yields; a new, inexpensive biological purification system could remove hydrogen sulphide contaminations; artificial fertilizer use could be reduced; crops absorbed processed manure better; processed manure had less pathogens and weeds if digestion occurred at high temperatures; biogas plants reduced greenhouse gas emissions because methane was collected and used (Raven and Geels 2010)

[10] Following the 1999 climate policy, a large research programme in renewable energy sources was funded, including biogas. However, regulatory problems regarding co-digestion of wastes caused bottlenecks in the system and (as in Denmark), with the liberalisation of the electricity system, there were also problems due to uncertainty of longer-term financing of projects. However when these were resolved, new projects went ahead (Raven and Geels 2010).

times provided an opportunity for centralised biogas plants, who had the capacity to store and distribute manure to farmers. Significant government (Danish Energy Agency and the Ministry of Agriculture) support was then given through the Biogas Action Programme established in 1988 (-2002), to support research and development, information dissemination activities, construction and monitoring of plants, investment grants, and loan schemes (ibid).

Raven and Geels (2010) discuss a number of factors which were instrumental in this Danish programme's success. Firstly, the bottom up approach adopted involved one or two biogas plants being constructed annually, thus allowing actors to build on previous learning experiences. A second factor was the building of relationships in a broad social network, involving policy makers, farmers, researchers, biogas plant suppliers, and biogas plant operators. Regular events enabled information to be disseminated and knowledge on technical, sanitary and social problems to be shared. These also spurred further research, which was used to inform new regulations. Thus broad learning processes involving multiple stakeholders and a wide range of dimensions occurred. One significant finding was the improvement of processes through co-digestion of other wastes. This added a waste processing function to plants, and as such social networks broadened to include waste management actors and the EPA. In addition to this involvement of a range of government actors, the growth of well-functioning farm co-operatives at a local level were also instrumental in success.

> Expectations, resources, learning processes, codification, and network building reinforced each other, creating internal momentum. Performance of centralised biogas plants improved, resulting in better economic feasibility. (Raven and Geels 2010:96)

However, as result of uncertainties following the liberalisation of the electricity market in 1996, the growth in biogas dwindled and investment in new biogas plants halted. Following the election of a new government in 2001, many grant and support schemes for renewable energy were discontinued, including the Biogas Action Programme. However, a number of developments which then ensued culminated in a renewed interest in farm-scale plants. On-going research and testing at the Nordic Folkecenter, including collaboration with German engineers meant that designs were technically improved. In addition, farms had grown in size and climate change had become an issue, resulting in the need to reduce emissions from agriculture. When eventually grants became available, farm-scale plants diffused rapidly.

The issue of agricultural waste was also a major driver of biogas development in Germany where, following reunification in 1990, the problem of dealing with manure on former East German collectives sparked a state funding programme for producers of biogas. In 1991, an Electricity Feed-in Law provided compensation for electricity from renewable sources fed into the grid, and this provided further financial incentive for farmers (Sutherland et al 2015). Biogas actors at this stage included the waste industry, industrial biogas plant operators and energy suppliers in addition to conventional farmers. Technological progress was mainly driven by practitioners, and by 1998 about 400 biogas plants were installed, mostly based on liquid manure in smaller animal production enterprises (ibid:1548).

Following these, a large number of government incentives have served to support the production and utilisation of bio-energy (Poeschl et al 2010) resulting in Germany becoming a leader in the field[11]. A Renewable Energy Law (EEG) introduced in 2000 (updated in 2014) guarantees long-term feed-in tariffs, and the sector has experienced increasing professionalization with 'turnkey' plants and services (set-up, monitoring, process steering) provided by expanding businesses (Sutherland et al 2015, IEA Bio-enegy Germany 2014). Responses to the climate crisis and the need to decommission existing nuclear plants have also driven the development of renewable energy sources. In 2005, a climate protection programme foregrounded renewable energies in innovation policies. Feed in tariffs meant that the cultivation of energy crops also expanded rapidly in this period, as it had become more economical for farmers to produce these. However with the global food crisis in 2007, awareness of the implications of this approach for food security and biodiversity have arisen, raising a major dilemma round continuity of supply of feedstocks (ibid).

[11] According to Energiewende, the German Environmental Ministry estimates that renewable energy made up around 11 percent of total energy consumption in 2013. Nearly 37 percent of that was biomass in the heat sector, along with over 10 percent biofuels and 15 percent biogas in the power sector. In total, bioenergy made up 62 percent of total renewable energy supply in Germany in 2013, equivalent to 7 percent of total energy consumption (2015:19).

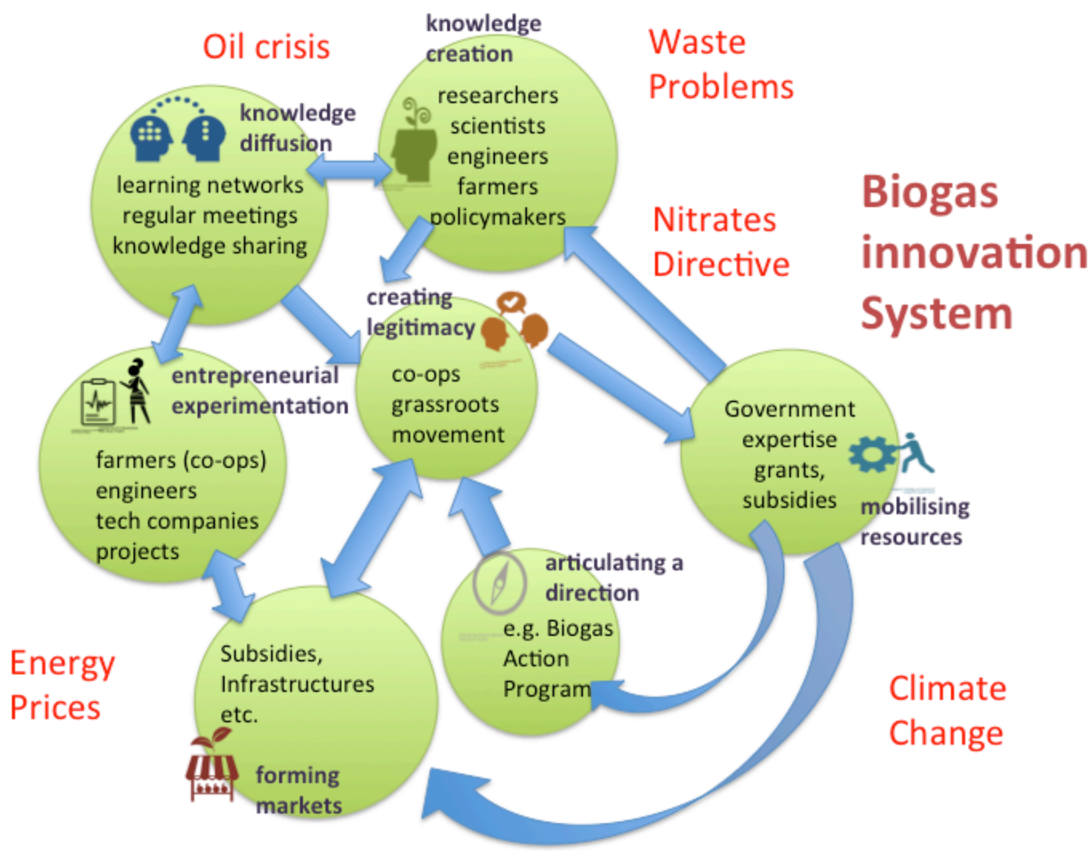


Fig 3.1: A Sketch of a Biogas Innovation system with Landscape Pressures[12]

It is possible to provide a schematic of the biogas innovation system (see Fig 3.1). Some of the key drivers in this system are discussed below.

3.3 Drivers, Barriers and Incentives

3.3.1 Landscape Drivers

It is clear from the above discussion that the interplay between drivers and barriers to the development of biogas operating at different levels (niche, regime, landscape), has resulted in different outcomes emerging in the national settings considered. In both Denmark and Germany, experimentation was initially driven by the search for alternative sources of energy driven by the oil crises in the 1970s. A further imperative was the need to deal with farm waste, resulting from the 1991 EU Nitrates Directive – this was a particular factor in the case of East German farming collectives, following German re-unification. Manure surplus problems in the Netherlands[13] in the 1990s also exerted strong pressure on Dutch agricultural regime actors to build large centralised biogas plants. An added bonus was that the co-digestion of municipal waste enabled the integration of waste management with energy generation, and also helped solve problems with excessive waste. A third major (landscape) driver was the need to address greenhouse gas emissions. Since

[12] Sketched based on material referenced in the discussions on biogas in Section 3.2, and on material referenced in the section on TIS functions described in Section 2.1 (Wieckzorek and Hekkert 2012, Raven and Geels 2010), icons sourced from noun project (www.thenounproject.com).

[13] Raven and Geels (2010) note these were larger than in Denmark.

1991, there have been a series of EU directives and a large amount of EU research funding dedicated to renewable energies including biogas technologies, innovation and processes which have (variously) translated to national policy. As such, subsidy schemes and investment grants have played a major role in addressing the wide range of barriers that have arisen in most of the countries examined.

3.2.2 Barriers

As discussed above, the development of biogas has been beset with a range of technical barriers, particularly in the earlier stages of development. Although most of these have been overcome, investment costs are high, and only economic for large-scale plants, or where subsidy favours smaller scale plants, as in Germany (Poeschl et al 2010). Significant barriers to the expanded utilisation of biogas still exist. Problems occur in the entire process chain: the need for a sustainable supply of feedstock and feedstock optimisation; biogas plant implementation; the management of anaerobic digestion processes; and the infrastructures and technologies needed for biogas distribution and use. As discussed above, barriers can arise in other regimes; for example co-processing of certain landfill wastes with farm wastes render higher yields but this is contingent on the amenability or ability of waste processors to provide a sufficient and sustainable supply of waste of the requisite quality[14] (Poeschl et al 2010). Infrastructural barriers include the need for a more robust electricity and gas grid infrastructure for easier access by biogas plants (ibid). In the Netherlands, a natural gas infrastructure and a ready supply of natural gas tended to limit opportunities to link biogas to heat generation, and attempts to inject biogas into this network met with a range of technical, logistical and communication problems (Smink et al 2015). To counter the effects of 'lock-in' with regard to existing gas infrastructures, a number of regulations setting targets for converting biogas to methane have driven an expansion of the use of technologies to upgrade biogas to biomethane in Germany (IEA Bioenergy Germany 2014).

The location of plants is also governed by environmental regulations and local acceptance may be determined by odour and noise levels, increase in traffic, and concerns about potential damage to landscape (such as environmental damage due to high concentration of nutrients from feedstock manures) (Poschl et al 2010, Bojesen et al 2015). Plants may also require road infrastructure to transport feedstock and outputs; the availability of adequate feedstock near the plant location significantly enhances the efficiency of operation (EEA 2013). Depending on fuel produced and its intended use, other factors determining the optimum location of plants might also require the existence of gas networks for bio-methane injection, and the transmission efficiency limitations of district heating grids (Poschl et al 2010).

3.2.3 Policy Incentives

In order to incentivise the production of biogas, a wide range of policy instruments have been used. Of note is Germany, where significant Government support for the production of farm-based biogas has encouraged its rapid development, rendering Germany one of the most experienced countries in

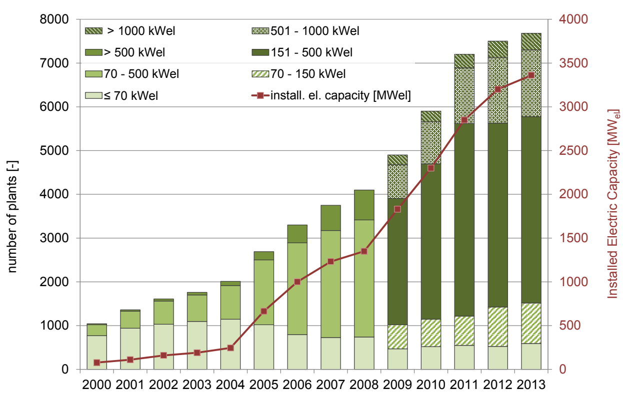
[14] Certain industrial waste streams, though they can have higher biogas yield, have higher energy costs associated with feedstock pre-treatment and sterilisation and are thus less sustainable. There is also is a significant knowledge gap on the co-digestion of food processing and MSW streams.

biogas in the EU (Poeschl et al 2010, Sutherland et al 2015, Energiewende 2015, IEA bio-energy Germany 2014). Most measures have come under the renewable energies act – EEG, although certain updates in 2014 (e.g. to cap return from “new” sources of bioelectricity), has led to a reduction in the number of new biogas plants (IEA Bio-energy Germany 2014). Financial incentives to drive biogas development, production and use have included:

- **Low-interest loans** for small-scale biogas plants;
- **Feed-in tariffs :** Fixed payments (feed-in tariffs) are offered for every kilowatt-hour of renewable electricity supplied to the national grid, for twenty years, but in every future year, the tariff is reduced by a certain percentage (dynamic reduction) to account for future cost reductions.
- **Bonus schemes** (simplified in 2014 but previously included: additional payments for the exclusive usage of renewable raw materials.; **bonuses for the co-generation of combined heat and power** for heat utilisation outside of the plant are aimed at encouraging higher energy conversion efficiency; an **innovation or technology bonus** is aimed at encouraging adoption of more efficient technologies, for example fuel cell technology, deployment of micro gas turbines, or the production of bio-methane; however these require a conversion efficiency greater than 45%.

(Poeschl 2010, IEA Bio-energy Germany 2014)

The remaining bonus schemes act as an incentive for small-scale biogas plants to use readily available liquid manure (they must use 80% manure). Effective since 2009, these schemes are intended to encourage small-scale decentralised units that promote rural development. The fact that liquid manure can be used as a feedstock without pre-treatment, and that energy production and recirculation of digestate through soil nutrients in closed CO_2 cycle provides scope for sustainable production, hence, expanded utilisation of biogas. For biogas-electricity from other organic wastes, there is a lower feed-in tariff and all systems must employ composting to treat the digestate (IEA Bioenergy Germany 2014). Other financial incentives include tax reliefs: biogas energy is exempt from energy tax when used with stationary plant, as an incentive for electricity generation.



Growth of Biogas Plants in Germany
Source: IEA Bioenergy Germany 2014:15

Infrastructural modifications, such as the extension of the DH network are also relevant to promotion of biogas technology in Germany. Upgraded biogas (biomethane) can be fed into natural gas distribution grids to supply heat or being used in CHP plants and as a transport fuel. A number of regulations have also helped to remove barriers to this (ibid). The Renewable Energy Heat Act (2009) place owners of newly constructed buildings under obligation to use renewable energy to meet a portion of their heat requirements; however it requires the use of highly efficient bioenergy sources (IEA Bio-energy Germany 2014).

In Denmark, areas which were not linked to the natural gas grid but possessed local heat infrastructure benefited from government policy to replace oil with biogas, using existing plants and infrastructures for heat distribution. Energy policy also had an effect. In contrast to the Dutch government, when oil prices lowered in the 1980s, the Danish government introduced high taxes on fossil fuels to improve the competitive conditions for domestic energy sources and stimulate the development of new industries. There were also a number of dedicated support programmes for farm-based biogas (the STUB programme in late 1970s and the Biogas Action Programme in late 1980s and 1990s). As in Germany, support had a more long-term and sustained character than in the Netherlands, where support tended to be ad hoc and intermittent (Raven and Geels 2010). Feed-in tariffs have existed since 2000 via the Biomass Agreement and support is now extended to all renewables and collected via a Public Service Obligation (PSO) tariff paid for by consumers. Currently, the 2012 Energy Agreement aims at producing 35% energy supply from renewables, with biogas being key to this. The emphasis is to move away from the use of energy crops, thus the ”Green Growth” initiative includes the objective that 50% of livestock manure is to be used for green energy by 2020. To aid in this major research area in Denmark involves examining which co-substrates can best be co- digested with slurry (IEA Bioenergy Denmark 2014). Table 3.1 summarises landscape drivers, barriers, incentives, and niche factors.

3.2.4 Transition Dynamics

Important factors in the growth of biogas in Denmark were strong niche-led processes of network formation, knowledge exchange and learning (Raven and Geels 2010). A strong grassroots movement with a continued commitment to alternative energies in the Nordic FolkeCenter meant that farm-based biogas production did not die out when technical difficulties emerged (in contrast to the Netherlands and Sweden). They also meant that there were actors consistently working to argue the legitimacy of this approach. The existence of and experience with farming co-operatives in the country meant that social networks tended to be stronger. Raven and Geels note that good management of internal niche processes (learning, expectation management, and social network dynamics) became more important as time went on, to nurture and develop the niche and enable it to survive on its own. Currently, biogas has a key designated role to play in an overall Danish energy transition, thus there is a clear future vision for the development of the niche.

The demand for vehicle gas was a major argument for increasing biogas production in Sweden. Here, the involvement of another regime added impetus, as major actors included the water companies who owned the sewage treatment plants, and thus stood to gain from the development of biogas capacity. Biogas here requires little import of feedstock: 97 percent of feedstock used to produce gas was from Sweden, and 98 percent of biogas used was produced from waste or residues (Svebio 2014), and thus can be viewed as contributing to energy independence. The use of bioenergy for transport was also well developed in Sweden, and there was a history of experimentation with biomethane and bioethanol as transport fuels. This will be examined in more detail in the next section, which looks at biofuels. To provide further background the broader context for a transition in transport is discussed in more detail in Box 4.

Landscape Influences/Drivers •Oil crisis •Farm Waste Problems •Climate Change •Move from nuclear •Liberalisation of electricity		
TIS Function	**Drivers/Incentives (niche and regime)**	**Barriers (niche and regime)**
Knowledge Development	Research projects Collaboration between farmers and universities (SE, NL, DK). Folke center kept research alive, collaboration with German engineers (DK)	Funding withdrawn (DK, NL)
Knowledge Dissemination	STUB (DK), Biogas Action Programme(DK) Bottom-up approach, network formation, knowledge exchange and learning processes prioritised(DK) Learning from other nations experience (NL).	Poor communication of results of experiments (NL) Failure to form learning networks (SE)
Entrepreneurial Activities	STUB(DK) assisted construction of seven farmscale plants enabing learning to occur on the technical and economic aspects of running biogas plants. Feed-in tariffs (DE, DK) Low interest loans for small-scale biogas plants, CHP bonus, Innovation bonus, Payments for use of renewable raw materials (DE)	Technical problems, limited economic benefit (DK, NL) Removal of subsidies Uncertainty of longer-term financing of projects (NL, DK). Problems with sourcing waste for co-digestion (NL) Unsustainable feedstock sources Regulatory problems re co-digestion of wastes caused bottlenecks (NL) High initial investment costs (all)
Direction of Search	2012 Energy Agreement – aim 35% energy supply from renewables, biogas being key to this(DK) Green Growth" initiative (DK) (50% of livestock manure is to be used for green energy by 2020) Renewable Energy Heat Act (2009) Renewable energies act (EEG) (DE)	Lack of overarching legislation, lack of policy coherence Support for natural gas and strong fossil fuel regime (NL).
Market Formation	Local heat infrastructures: • Extension of DH network (DK) • Use of natural gas distribution grids to supply heat (DE) Use as transport fuel. High taxes on fossil fuels (DK) Tax exemptions for Renewables (DK, SE) Production of fertiliser	Cost (if not subsidised). Need for electricity and gas grid infrastructure with easier access for biogas plants (DE, NL). Need for road infrastructure Problems with product (explosive fertiliser in NL) Transmission efficiency.
Resource Mobilisation	Range of experts were mobilized through STUB(DK) Investment grants, subsidies Certainty for investors due to longer term subsidies (DK, DE)	Support ad hoc and intermittent Uncertainty for investors(NL)
Legitimation	Bottom-up approach, farmer's co-ops, grassroots innovators(DK) Production of biofuels, treatment of sewage (SE).	Unsustainability of feedstock. Environmental regulations. Local acceptance issues : odour and noise levels, potential increase in traffic, concerns on potential damage to landscape.(all)

Table 3.1 : Summary of Barriers and Drivers/Incentives to the Production of Biogas using Farm Waste.

Box 3 : The Importance of a Systemic Approach: Transitions in Transport

The consideration of any technology to be used in transport needs to be considered in the context of the transport (or mobility) sector as a whole. Turnheim et al (2014) consider personal mobility as a 'derived demand' which involves getting access to places for particular reasons (work, food, leisure, etc.). A more sustainable transport sector thus requires changes in practices, planning, and infrastructural and service provision as much as changes in technology and how it is used. In particular, changes in transport practices require the active involvement of users, coupled with the infrastructure to enable this.

Landscape Drivers

Geels (2012) cites a wide range of landscape factors affecting transport systems in general and personal mobility in particular. These include growing awareness of responding to climate change and the large contribution of transport to global emissions. This is reflected in EU targets and national government responses to these. Other factors cited include extreme weather events; increased awareness of issues of climate justice, pollution and congestion; and an increase in cycling and walking for health purposes. These factors lead to pressure for improved infrastructure to enable more alternative or intermodal forms of transport such as bicycle lanes, park and ride facilities, or different sharing mechanisms. However, despite these, strong forces ensure that the private car retains dominance. Aspects of the physical landscape - networks of roads and streets, the spatial layout of housing and workplaces favour the private car. For example the large dispersed rural population in Ireland coupled with a poor or absent public transport system practically necessitates its use.

Path Dependencies and the Transport Regime

In addition to the strong dominance of the fossil fuel regime and a transport regime (legislation, infrastructure provision, firms, markets etc.) including a road infrastructure largely orientated towards the use of motorised transport, the private car is also privileged by broader cultural factors. These include a preference for private property rather than collective ownership and use; they bolster feelings of autonomy and privacy (Geels 2012) and affirm values such as freedom, choice, progress, wealth, and status; and feelings of autonomy and privacy, effectively acting as 'cocoons' (Wells and Xenios 2015). In general fossil-fuelled private cars tend to be a faster mode of transport, thus more 'convenient' and travel further than electric vehicles. These cultures manifest in deeply entrenched practices and habits (Turnheim et al 2014). Problems such as traffic congestion and pollution have the capacity to disrupt these patterns and habits.

Niches in Transport: Systems, Practices, Technologies, Communities, Business models

More fundamental (and ultimately more sustainable) changes in personal mobility include niches such as inter-modal transport, improved public transport provision, transport management, sustainable urban planning, and car and bike-sharing (Geels 2012, Turnheim et al 2014). However as the dominant transport regime in most countries (including Ireland – see Browne et al 2011) is based on the fossil-fuel powered private car, much research has focused on the development and use of renewable fuels, and the development of vehicles to accommodate these. Renewable energy technologies in transport include the use of 100% liquid biofuels or blended biofuels with conventional fuels – these can be first or second generation; biogas from the digestion or gasification of biomass; hydrogen (FCV); and electric vehicles of different types (BEV, HEV etc.) (Farla et al 2010, Ren21 2015). Two technologies to be considered - biofuels and electric vehicles – are largely compatible with private car ownership. However, questions exist over their ultimate sustainability, and the need for transition in the transport situation as a whole.

4. Case 2: Biofuels

Given that 42% of energy used in Ireland is consumed in the transport sector (SEAI 2015), emiting 19% of greenhouse gases, there is a clear need to consider more sustainable fuels, although as Box 4 has stressed, this needs to be in the context of a broader systemic approach. In the transport sector globally, the primary focus to date has largely been on liquid biofuels. One significant factor in the growth of the use of biofuels has been their relative compatibility with existing modes of transport (Turnheim et al 2014). This technological case study examines the development of biofuels in Sweden, where 12.6% of all fuels consumed for transport in 2012 were from renewable sources (Svebio 2014). It also examines the somewhat less successful development of biofuels in the Netherlands. Sweden provides a useful illustration of the dynamics of the successful growth of an alternative fuel niche, which also raises potential problems of "lock-in" to a less sustainable fuel source (OECD 2011[15]:117). The Netherlands illustrates the shaping effect of an incumbent fossil fuel regime – a major emphasis being on fuel blending. However it also shows how concern regarding the sustainability of biofuels served to reframe the Dutch (and also EU) biofuels agenda (Ulmanen et al 2009).

As discussed in Box 1, growth in biofuels has slowed down due to concern over the use of food-producing land for energy crops, and the subsequent introduction by the EU of a set of sustainability criteria for biofuels. According to the EU, to be considered sustainable, biofuels must currently achieve greenhouse gas savings of at least 35% in comparison to fossil fuels, rising to 50% in 2017. In 2018, this rises again to 60% but only for new production plants. All life cycle emissions are taken into account when calculating greenhouse gas savings, including emissions from cultivation, processing, and transport (EU 2015[16]).

4.1 Description of the Technology

As illustrated in Box 2, a range of technologies may be involved at different stages in the production of biofuels, depending on the type of feedstock and process used. Prior to the introduction of sustainability criteria, the distinction between 'first generation' (1G) biofuels and 'second generation' (2G) biofuels was made when selecting technologies to prioritise in the Dutch GAVE research programme in the late 1990s (Suurs and Hekkert 2009). The distinction has largely been made due to the need to account for indirect land use change (ILUC) caused by fuel crops displacing food crops or causing biodiversity loss. 1G biofuels are derived from energy crops, such as ethanol from corn or sugarbeet, or biodiesel from rapeseed. These tend to require much less processing: certain vegetable oils can be used directly in modified diesel engines; ethanol can be produced through fermentation processes. 2G fuels are typically produced from waste products, such as ethanol or synthetic diesel from lignocelluloses (woody biomass). They work with agricultural, industrial, forestry or municipal wastes, thus don't displace other land uses. However they require more processing (thermochemical or biochemical), and many technologies to process different types of by-product or waste are undergoing rapid development and thus uncertainty in forecasting exists (Hellsmark and Jacobsson 2012, Farla et al 2010).

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[15] OECD Economic Surveys: Sweden 2011

[16] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/sustainability-criteria

Small percentages of biofuels can be blended with petrol or diesel in conventional engines, or in greater proportions in flexi-fuel engines (FFVs). Diesel engines can also be converted for use with biodiesel. Biogas uses the same technology as natural gas engines and growing quantities of bio-methane are also used to fuel cars, buses, and other vehicles in several EU countries, in particular Germany, Finland, and Sweden (Ren21 2015:35).

4.2 Contextual Analysis : Development of Biofuels in Sweden and the Netherlands

As discussed above, Sweden has been a highly successful innovator of biofuels, the main fuels developed being alcohols (methanol, ethanol) and biogas. Early and continued research and experimentation together with consistent government support have contributed to the emergence of viable market niches in ethanol and (bio)gas, in contrast to a small and fragile biodiesel niche in the Netherlands (Ulamannen et al 2009)[17]. In Sweden, biofuels had been produced since World War 2 for political and military reasons, notably ethanol (industrial alcohol) produced from sulphate lye, a waste product from the paper pulp industry (Ulmanen et al 2009). This provided a knowledge base for future developments (Klitkou et al 2015). The oil crises in the 1970s triggered a number of experiments marking the beginning of a phase described by Hillman and Sanden (2008) as dominated by research, development and the building of national competence into the production and use of methanol as a fuel. In 1973, the carmaker Volvo, working in a joint venture with the Swedish government experimented with methanol as a fuel substitute and carried out small scale trials using pure fuels and blends. In 1979, a larger experiment was funded involving 1000 cars and an upgrade of the filling station network to supply a blended fuel (Ulmanen et al 2009). Following the 1979 oil crisis, alternative fuel development for the transport sector became a policy priority, one strand of which was to develop biomass gasification technology to produce methanol from domestic raw materials such as peat and wood. Further incentives for development were passed in legislation in 1981, which made alcohol fuels tax-exempt. A trial was also funded of 200-300 cars and 100 buses, mainly FFVs supplied by Volvo and Saab-Scania(ibid).

Impetus for production of ethanol from sugar beet and wheat in the 1980s came from the Federation of Swedish Farmers who had significant influence on the government (Ulmanen el al 2009). With government subsidies, an ethanol plant was built in Linkoping in South Sweden in collaboration with an oil distribution company (OK), and this produced alcohol from 1984-1987 (ibid). In the North of Sweden, another coalition of actors, SSEU[18], made up of forest owners, farmers, local and national government actors, and chemical processing companies, came together and built a plant producing ethanol from wood products. Trials were conducted, and further funding for research and scaling up of the project was garnered by SSEU in the early 1990s. In 1996, 300 buses and 24 trucks were running on ethanol, and ethanol FFVs and fuel pumps spread to local authority fleets all over Sweden, following a promotion tour by SSEU which also involved the environmental organisation the Natural Step (ibid). This demonstrates the effectiveness of a strong

[17] In the early 1990s, bus trials using biogas were also set up in a couple of cities, including Linkoping (Fallde and Eklund 2015). Biogas engines used the same technology as natural gas, and thus benefitted from technological developments in that area. In addition, all the policy measures for green fuels, including incentives for filling stations to supply alternative fuels, also applied to biogas.

[18] Foundation for Swedish Ethanol Development (SSEU).

network of niche actors, working to create legitimacy. In the late 1990s, the government provided additional support for FFVs and filling stations via local investment programs (Ulmanen el al 2009). Hillman and Sanden (2008) describe the major motivation at this stage as reducing local air pollution, and note that this built knowledge, networks and a stock of artefacts.

From the late 1990s, climate change became an important issue, and the EU biofuels directive was introduced in 2003. This coupled with the need to reduce CO_2 emissions led to a host of additional incentives to encourage to the use of biofuels by the Swedish government, including tax reduction on environmentally friendly cars (2000); investment programs and local initiatives such as free parking and exemption from congestion fees (2005). Filling stations with sales above a particular level were also obliged to supply at least one renewable fuel, with grants to supply fuels other than ethanol (Hillman and Sanden 2008). The effect of these measures on the availability of ethanol in filling stations is illustrated clearly in Fig 4.1., the poor availability of EV charging poles reflected in a slow growth in the registration of electric vehicles, though this has increased recently (SCB 2015).

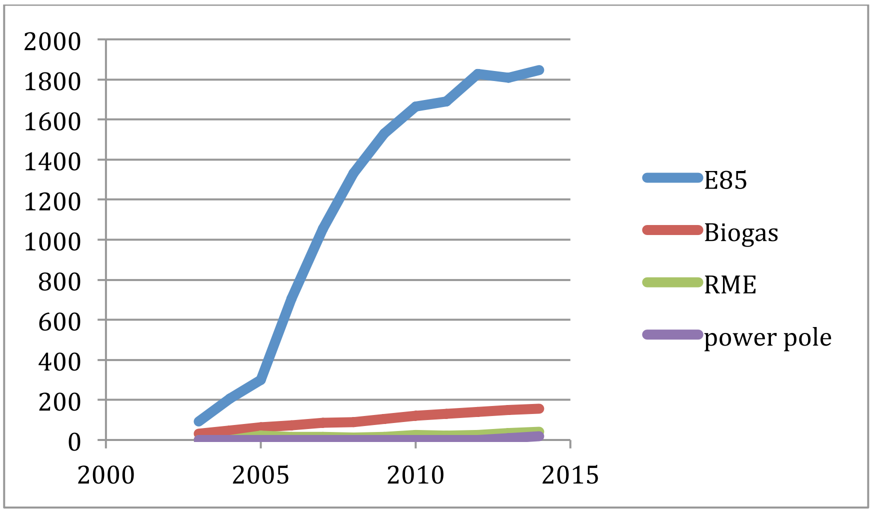

Fig 4.1 Growth in number of Fuel stations offering renewable fuels[19].

Sweden currently has a national transport plan (2014-2025) and aims at having a vehicle fleet independent of fossil fuels by 2030. These aims are to be achieved via the development of attractive and accessible cities, infrastructure measures such as cycling paths and better rail services, more efficient vehicles, and the use of biofuels and electric vehicles (Svebio 2014). A range of tax measures incentivises the use of low and zero emission cars, and there is a compulsory biofuel quota system. Liquid biofuels must now comply with EU sustainability requirements (EU 2009). This approach shows that, to some extent, the government have recognised the danger of 'lock-in' to biofuels (OECD 2011). The 2015 figures indicate a marked decline in the registration of flexi-fuel ethanol vehicles and a small increase in electric and hybrid vehicles (SCB 2015)[20]. Klitkou et al (2015) cite sustainability questions relating to land use, possible negative health effects and perceived engine damage as factors which may be contributing to this decline.

In contrast to Sweden, biofuel development in the Netherlands has been intermittent, characterised by a 'hype- disappointment cycle' (Alkemade and Suurs 2012), and mainly dominated by biofuel

[19] Source of Data: spbi.se (accessed 11-11-2015)

[20] Statistics Sweden: Traffic Analysis November 2015: www.scb.se

blending (Turnheim et al 2014), unsurprising given the dominance of the Dutch fossil fuel (gas and oil) regime. As such, this also illustrates how a strong incumbent regime can shape the nature of change. The Netherlands also provides an example of where concerns raised about the sustainability of biofuels (see Box 1) resulted in a new distinction being created between more and less sustainable biofuels. Small biofuel developments started out in the 1990s as practical trials by entrepreneurs and local authorities with very little government support. One of these involved boat owners using vegetable oil as a boat fuel, in order to reduce water pollution (Suurs and Hekkert 2009). In another, the 'agrification'[21] movement and environmentalists formed a lobby group to drive the production of ethanol from excess crops, with the aim of reducing air pollution. Subsequent attempts to build an ethanol plant received intermittent support from government and private investors, but a plant was not built, despite tax reductions and subsidies offered, as it was not economically viable (ibid). The dominance of the fossil fuel regime in the Netherlands, including a well-established infrastructure of oil and gas refineries and the strong role played by oil companies in natural gas extraction meant that the main alternative fuel considered was LPG (liquefied petroleum gas), a by-product of the oil industry (Ulmanen et al 2009). In response to the 2003 EU biofuels directive, the Dutch Government legislated, requiring a percentage of biofuels to be sold by oil companies. Money was allocated for further research, and subsidies were given to production projects. This drove entrepreneurs and a number of start-ups were created, including a series of entrepreneurial projects in rural areas (Suurs and Hekkert, 2009), for example, Ulmanen et al note that tax exemptions enabled a small market niche for biodiesel to be constructed, despite problems with supply of rapeseed from farmers (2009), and there were a number of experiments in public transport by local authorities.

Significantly, the emergence of questions of food security and the sustainability of biofuels had a distinct impact on biofuel development in the Netherlands (Suurs and Hekkert 2009). One factor particular to the Netherlands was the GAVE[22] research programme established at the end of the 1990s , which aimed to carry out a detailed study, establishing the viability of biofuels. A pre-study listing fuel production chains for further assessment recommended that only biofuels which would result in an 80% reduction in CO_2 emissions should be considered. This resulted in a distinction being made between the less sustainable first generation (1G) biofuels and second generation (2G) biofuels which would meet these criteria (Suurs and Hekkert 2009). This provided a focus for a 2G biofuel network to emerge, the GAVE programme acting as a catalyst, "bundling and connecting activities that, until now, had been developing in relative isolation" (ibid:1012). A number of major projects to develop 2G biofuels were begun involving scientists and technology developers, a major theme being the production of Fischer-Tropsch (FT) Diesel. However, according to Ulmanen et al (2009), no demonstration plants emerged from these projects initially, the main reasons being severe bottlenecks in the development of gas-cleaning techniques (ultimately solved) and limited financial support[23]. At this point, market formation become GAVE's new task (Suurs and Hekkert 2009). Despite the existence of some pilot and commercial plants, Turnheim et al(2014) note that

[21] The term 'agrification' was introduced in the Netherlands and other European countries in the 1980s to refer to the non-food applications for agricultural produce.

[22] National programme for the assessment and support of gaseous and liquid CO_2-neutral energy carriers.

[23] The amount of subsidy being offered by GAVE did not incentivise the companies involved to continue. Following EU pressure regarding biofuels, industry actors pressured the government to provide tax exemptions for biofuels projects, which were ultimately granted (Suurs and Hekkert 2009).

there are still distinct questions regarding commercial viability of 2G biofuels, and the ability to sustainably scale up production. In fact, the high costs involved in producing demonstration plants for FT-diesel and other 2G biofuels have led authors such as Hellsmark and Jacobssen (2012) to advocate demonstration plants at a European level. This would have the advantage of pooling resources and enabling knowledge sharing. 2G biofuels still therefore can still be considered to be in the early stages of development.

4.3 Drivers, Barriers and Incentives

4.3.1 Landscape Drivers

Broader landscape factors, and the existence of strong incumbent regimes have shaped the differential development of biofuels in Sweden and the Netherlands: Sweden had an established car industry and a high availability of wood, whereas the Netherlands had a powerful and well-established oil and gas industry. In both countries, in addition to climate change, motivational factors in the development of biofuels have included oil shortages, the need to reduce air (reducing urban smog) and water pollution, and the need to deal with excess waste (Hillman and Sanden 2008, Ulmanen et al 2009). The 2003 EU directive (2003/30/EC) on biofuels acted as a strong driver and a large number of research and demonstration projects were funded at both EU and national levels. For example, Suurs and Hekkert note that in the Netherlands, this stimulated small-scale biofuels development and the growth of networks (2009). Later concerns (and subsequent amendments to EU directives concerning the sustainability of biofuels) have also had a dampening influence on biofuels development in the Netherlands, and have raised the danger of 'lock-in' to what may prove to be an ultimately unsustainable niche in Sweden.

4.3.2 Barriers

Barriers to the development and diffusion of biofuels include insecurity of feedstock supply; technical difficulties in processing, and problems with markets and distribution. Technical difficulties have included describing and measuring quality and energy content in adequate and efficient ways; risk of contamination; and durability and storability of fuels (Ulmanen et al 2009, Svebio 2014). A number of cost barriers also arise for biofuel producers. These include uncertainties regarding future (feedstock) prices and costs associated with shipping biomass. For example, ships and harbour facilities are often not equipped to enable cost efficient handling and storage of biomass for energy, although this is less severe for liquid biofuels as existing technology for oil, etc. can be used (Svebio 2014). Environmental and social problems may be associated with the siting of facilities, such as risk of health or eco-system damage.

As discussed above, the development of a market for biofuels relies on infrastructure for distribution, the existence of a petrol/diesel distribution network has to some extent eased their introduction, as these existing filling stations could be incentivised to supply liquid or gaseous biofuels. It also requires flexi-fuel vehicles to be available on the market of sufficient quality and affordable costs (Ulmanen et al 2009). Where these are absent, there are significant barriers to market growth. Scepticism towards biofuels from vehicle owners requires focus on quality in order to increase customer's willingness to use high blend biofuels and to accept higher blending volumes in gasoline and diesel (Svebio 2014). Lack of consistency or continuity of government support has been a major factor affecting biofuels development in the Netherlands, and this has been interpreted as a 'hype/disappointment cycle' (Alkemade and Suurs 2012).

The most significant barriers to biofuels development have been the legitimacy problems which have emerged regarding the sustainability of feedstock production, and the relative carbon intensity of producing and consuming fuels. To produce sustainable biofuels, as per EU sustainability criteria, carbon costs incurred through supply chains, processes or products all need to be taken into account (Svebio 2014). The effect of indirect land use (ILUC) is discussed in more detail in Box 1.

4.3.3 Policy Incentives[24]

A number of policy measures have been used to incentivise the use of biofuels. These include production-oriented measures such as grants for developers and producers and more market oriented measures such as subsidies and other benefits for consumers. Regulatory measures have been used to ensure the development of supply networks, and it has also been financially beneficial for petrol companies to blend in biofuels in their gasoline and diesel. Ulmanen et al (2009) note that in Sweden, the emphasis has been on a market and consumer-oriented strategy in contrast to a fuel supply and technology focus in the Netherlands. Sweden has also adopted a more holistic approach to the use of biofuels, considering alternative modes of transport in the context of health and well-being and planning as a whole (Svebio 2014).

Financial resources, such as grants from public authorities, and R&D funds from the local, national and European governments in addition to the contributions of funds and expertise by private industry actors (such as Nedalco in the Netherlands and Volvo in Sweden) have played a large role in the development of biofuels in both countries (Suurs and Hekkert 2009, Ulmanen et al 2009). In the Netherlands, experimentation with biofuels was supported by the Dutch government and regional actors in the early 1990s via research/trial funding and tax exemptions to support biofuel vehicle experiments; however the emergence of an anti-biofuel coalition from the mid-1990s resulted in a shifting of R&D funding to 2G biofuels (Turnheim et al 2014). As discussed above, there has also been significant investment in biofuel development in Sweden, beginning in the 1970s, but building on a more established knowledge base, as ethanol had been produced since World War 2.

Regulatory measures have also driven development of infrastructure, and infrastructural investment was included in many of the earlier biofuel experiments in Sweden. In Sweden the "Pumplagen" law states that filling stations that sell more than 1500 m3 must provide a biofuel option. The success of these measures can be seen through the growth in the number of filling stations having a various biofuel options -see Fig 4.1. In the Netherlands, the Dutch biofuels obligation (introduced 2007) requires fuel suppliers to include a minimum share of biofuels in their sales (Turnheim et al 2014, Svebio 2014).

To address cost barriers for customers and producers, enabling market formation, tax exemptions have also played a role, particularly in Sweden, where biofuels have traditionally been omitted from energy and CO_2 taxes and it has almost always been cheaper to use biofuels then fossil fuels (Svebio

[24] Browne et al (2012) provide a comprehensive list of more practical barriers to the use of alternative fuel vehicles of different types, assessing these as to their relevance and outlining policy measures and implications.

2014). According to the IEA, successful market growth of biofuels in Sweden is due to economic viability, customer demand and subsidies on fossil independent vehicles (Svebio 2014). The introduction of electricity certificates and tradable emission rights, have also meant that the process industries, in particular the forest industries, have increased their use of biomass fuels. However, these benefits are to be gradually reduced to follow EU rules regarding overcompensation, where biofuels cannot receive subsidies if the subsidies make them more price-competitive compared to fossil fuels (ibid). Further incentives for consumers include an exemption for ''environmental cars'' (including biofuel vehicles) from paying parking fees and congestion charges in certain Swedish cities (Suurs and Hekkert, Ulmanen et al 2009, Svebio 2014).

4.3.4 Transition Dynamics

In Sweden, developments started much earlier than in the Netherlands, and the fact that ethanol had been produced since World War 2 meant that there were established knowledge networks, which produced "learning effects" (Klitkou et al 2015). The involvement of key regime actors such as car companies, water treatment companies, and strong agricultural and forestry lobbies added legitimacy and provided strong cases for government support which was highly effective in seeding knowledge production and infrastructure provision. However, more recent concerns, such as those raised by Kiltkou et al (2015) regarding sustainability, health and reliability, reflected in registration figures (see Fig 4.2) indicate the possibility of a backlash occurring. However it is also interesting to compare this graph with Fig 5.1 (crude oil prices). One important point is that in Sweden, biofuels have been considered in the context of an overall societal energy transition, involving a transformation of the transport regime. Many measures in both Sweden (and some in the Netherlands) involved the use of alternative fuels in public transport fleets. However, particularly in cities, alternative fuels and modes of transport play a key role as components of a society-wide sustainability transition.

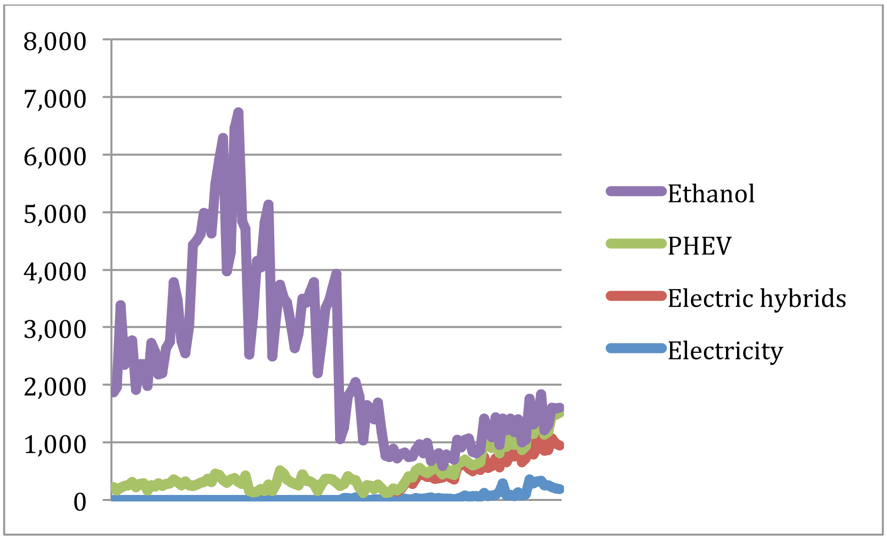

Fig 4.2 Registration of "green" cars in Sweden (Jan 2006- Nov 2015, SCB 2015[25])

[25] http://www.scb.se/en_/Finding-statistics/Statistics-by-subject-area/Transport-and-communications/Road-traffic/Registered-vehicles/

Landscape Influences •War (WW2) •Oil crisis •Car industry •Air/Water pollution •Forestry •Waste reduction •EU biofuels directive (2003)		
TIS Function	**Drivers**	**Barriers**
Knowledge Development	Research projects funded by govt (SE, NL) Early research into ethanol since WW2(SE) Development of flexi-fuel vehicles (FFVs) GAVE Project (NL)	Technical problems with 2G biofuel production processes. Difficulty of measuring/assessing sustainability.
Knowledge Dissemination	Building of diverse public/private networks (SE). GAVE programme acting as a catalyst, "bundling and connecting activities developing in relative isolation" (NL)	Difficulties in describing and measuring quality and energy content in adequate and efficient ways
Entrepreneurial Activities	Involvement of car industry e.g. Volvo in methanol experiments in 1970s(SE). Collaboration between farmers and fuel producers to produce ethanol (SE). Small experiments on biodiesel: boat-owners with biodiesel (NL). Entrepreneurial projects in rural areas, public investments aligned with these. Experiments on use of ethanol in buses funded by private companies with EU subsidies (NL) Filling stations must provide a biofuel option (SE) Electricity certificates (SE)	Difficulties in building biofuel production plants (locations, permits) Uncertainties regarding future (feedstock) prices and the sustainability performance of biofuels. Large role of incumbents in the current biofuels market Costs in shipping biomass for energy (SE)- shipping and harbour facilities don't always enable cost efficient handling and storage of biomass.
Direction of Search	Alternative fuels became policy priority after 1979 oil crisis (SE) EU Biofuels directive (2003) National transport plan (2014-2025) aims at having a vehicle fleet independent of fossil fuels by 2030 (SE) Swedish policy broader and consistent. Pollution standards Dutch biofuels obligation (2007)	Support for natural gas and strong fossil fuel regime (NL). Confusion regarding sustainability of fuels. Netherlands more technology-focused.
Market Formation	Broad market and consumer-oriented strategy (SE). Compatibility with existing forms of transport. Biofuels omitted from energy and CO_2 taxes(SE)- cheaper to use biofuels. Public transport and local authority fleets used for experiments including bus trials on biogas (same engines as LPG). Tax exemptions on environmentally friendly cars (2000) Local initiatives: free parking, exemption from congestion fees (2005). Filling stations obliged to supply at least one renewable fuel, with grants to supply fuels other than ethanol (SE) Legislation requiring a percentage of biofuels to be sold by oil companies (NL).	Need for filling station infrastructure Number of flexi-fuel vehicles Dominance of the fossil fuel regime in the Netherlands- well-established infrastructure of oil and gas refineries and the strong role played by oil companies in natural gas extraction meant that the main alternative fuel considered was LPG (liquefied petroleum gas), a by-product of the oil industry
Resource Mobilisation	Investment grants, subsidies. grants from public authorities, such as subsidies and R&D funds from the local,	Support ad hoc and intermittent (NL) Uncertainty for investors lack of continuity and

	national and European governments, matched by private industry actors such as Nedalco and Volvo	(hype/disappointment cycle) (NL) lack of a sustained supply of feedstock
Legitimation	Agrification movement and environmentalists formed a lobby group to drive the production of ethanol from excess crops to reduce air pollution(NL). Technically successful experiments.	Unsustainability of biofuels- emergence of an anti-biofuel coalition from the mid-1990s (NL) Environmental and social problems associated with the siting of facilities Carbon costs incurred through supply chains, processes or products Contamination, durability, storability, and health risks.

Table 4.1 : Summary and Examples of Drivers, Incentives and Barriers to Biofuel development

5. Electric Vehicles

Fully electric vehicles (FEVs) have no tailpipe emissions, thus contribute to air quality, and CO_2 emissions from use are dependent on the sources used to generate electricity. As they can be charged at off-peak times, they can also play a role in balancing the load on electricity systems largely based on renewable energy, although this function remains at demonstration stage (Ren21 2015). In Ireland the potential role of FEVs in balancing electricity load through "smart" recharging has been raised as a potential component of Ireland's energy transition (e.g. SEAI 2011). In Ireland 0.37% of cars (about 465) newly registered by December 2015 were electric[26], which indicates a comparatively low adoption rate. Paper 4 will explore the possible reasons for this in more detail.

FEVs mainly position themselves as an alternative to Internal Combustion Engine (ICE) vehicles, and use existing road infrastructures, though most are limited to smaller roads and have limited range (i.e. the distance they can drive on a fully charged battery)(Turnheim et al 2014). These limitations have tended to restrict their diffusion, despite the fact that reduced production costs (Nykvist and Nilsson 2015[27]) have contributed to models being developed at more competitive prices, and most major car companies have produced, or are currently developing electric vehicles. More recently, the launch of newer EV models such as the Tesla Model S series with improved battery technology and ranges up to 330 miles/528km,[28] [29] might indicate that electric vehicles are potentially at a "take-off" point. However high end vehicles are still very expensive, and questions exist regarding the ultimate sustainability of lithium batteries.

The number of electric passenger vehicles on the road globally nearly doubled from 350,000 in 2013 to 665,000 in 2014 (Ren21 2015:117). As they have tended to be more expensive, the sector has mainly grown where their use has been incentivised. One country where this has particularly been the case has been Norway, where over 33% of all new cars registered in 2015 were fully electric (Forbes 23-7-2015[30]), and this example will be discussed in more detail below.

5.1 Description of the Technology

The main components of a fully electric vehicle are a battery and an electric motor, the most critical of these being the battery (Turnheim et al 2013). They are typically charged by plugging into the electricity mains or renewable energy charging stations. The EU have agreed a Type-2 plug, and Mode 3 charging as European standards (Bakker 2013[31]). Full electric vehicles operate on electricity alone whereas hybrids and plug-in hybrids (PHEVs) also have internal combustion engine (ICE) capability.

5.2 Contextual Analysis: Development of Electric Vehicles in Norway and the Netherlands

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[26] Irish Motorstats [accessed http://www.beepbeep.ie/stats 15-12-2015]

[27] Industry-wide cost estimates declined by approx 14% p/a between 2007 and 2014; the cost of battery packs used by market-leading BEV manufacturers declined by 8% annually and continue to decline. Nykvist and Nilsson believe that this has significant implications for the assumptions used when modelling future energy and transport systems and permits an optimistic outlook for BEVs contributing to low-carbon transport. (Nykvist and Nilsson 2015)

[28] [http://www.teslamotors.com/en_GB/models accessed 15-12-2015]

[29] In comparison, the maximum range of the Nissan Leaf is 124 miles/(122-199km per charge depending on driving style. [http://www.nissan.ie/experience-nissan/range-nissan-leaf accessed 15-12-2015]

[30] http://www.forbes.com/sites/niallmccarthy/2015/07/23/norway-leads-the-worlds-market-for-electric-vehicles-infographic/

[31] http://e-mobility-nsr.eu/fileadmin/user_upload/downloads/info-pool/4.4_E-MobilityNSR_Recharging_infrastructure_standardization.pdf

See also http://e-mobility-nsr.eu/background/ - project set up to coordinate e-mobility in Europe.

Electric vehicles are a relatively mature technology, and have been in existence since the end of the 18th century (Sovacool 2009). Interest began to grow in the 1960s and 70s in the US, mainly due to air pollution and rising prices (Kemp 2012). However, performance has typically been poor compared to conventional vehicles, and by the end of the 1970s, less than 4000 FEVs had been sold worldwide (Dijk et al 2013). EU environmental policies the late 1980s and early 1990s, paralleled by developments in California where there was a regulatory push for zero emissions vehicles provided a further impetus (ibid). Engineering schools in Germany, Denmark and Switzerland became interested, and a number of governments sponsored research, and demonstration projects, including France, Switzerland and Norway (ibid). Despite the popularity of these, they did not lead to sales beyond the experiment. The most successful promotion of EVs to date has been in Norway (see also Paper 2). Targeted supports given by the Norwegian government over five phases of development since the 1970s, described by Figenbaum et al (2015), have been instrumental in this.

At an early stage, concept development (1970-1990) was characterised by support for research and the production of prototypes. Testing (1990-1999) and initial attempts at commercialisation were aided by a public test program. At this stage, a range of incentives to adopt EVs such as free parking and exemption from the registration tax, toll charges and the vehicle license fee were also put in place. NEVA, the Norwegian electric vehicle association was also set up. However sales remained slow and the Norwegian e-car company Th!nk went out of business(ibid).

At the early market stage (1999-2009), new incentives were introduced such as the ability to use bus lanes in Oslo, which succeeded in generating sales in that region. Th!nk was bought by Ford, but despite growth in indigenous capacity sales were slow. Ford sold Th!nk- and it was bought by Norwegian investors. Finally, at the market introduction stage (2009-2012), the centrality of the climate change agenda, and improved battery technologies led to renewed developments. These were aided by new models having been developed, which had higher safety levels, longer battery warranties and more comfort. Figenbaum et al note that these marked an improvement for Norwegians, as they compared favourably with previous models which had been available. They also note that NEVA developed into an important organisation over this period, facilitating knowledge transfer, and offering test drives. Further support was provided by a government agency Transnova, which was founded to support sustainable transport (ibid). In the current market expansion phase (2013-) the culmination of a series of incremental measures taken by the Norwegian government (in particular ability for EV drivers to use bus lanes), coupled with the market availability of improved EV models from major car manufacturers has resulted in a major expansion in sales, as mentioned above (33% of new cars registered in 2015 have been EVs (Forbes 23-7-2015[32]).

Supportive policy measures for EVs have also driven their growth in the Netherlands, which differed from Denmark and Norway in prioritising hybrid (PHEVs) as well as fully electric vehicles. This case, described by Boon and Bakker (2015) provides an example of where many initial policy measures (which effectively provided shielding for the EV niche) – tax exemptions and the organisation of infrastructural investments - taken were later changed, following subsequent evaluation or 'policy learning'. Initially, EVs and PHEVs in the Netherlands were exempted from registration tax for vehicles, yearly road use taxes, and income tax paid for the private use of company cars, and this made the Netherlands one of the most attractive places to market them. However, due to a rapid

[32] http://www.forbes.com/sites/niallmccarthy/2015/07/23/norway-leads-the-worlds-market-for-electric-vehicles-infographic/

take-up of EVs and particularly PHEVs, these proved to be prohibitively expensive for the government, and in 2014, the tax benefits were reduced.

To build infrastructure, between 2010 and 2013 charging points in public spaces were installed by electricity grid operators. These, together with the hundreds of chargers that were installed on behalf of the four largest cities in the Netherlands, form the backbone of the public recharging infrastructure. However, following a change in government in 2010, the responsibility for EVs was shifted from the Department of Infrastructure and the Environment to the Department of Economic Affairs, who had a different set of priorities (Van Der Steen et al 2014). After 2013, the grid operators were no longer allowed to install charging points as the government wanted to encourage private operators (Boon and Bakker 2015); however this proved to be less effective. According to Boon and Bakker:

> Learning took place regarding the tools for protection; semi-public investments by grid operators were not acceptable from a market-development perspective (2015:14).

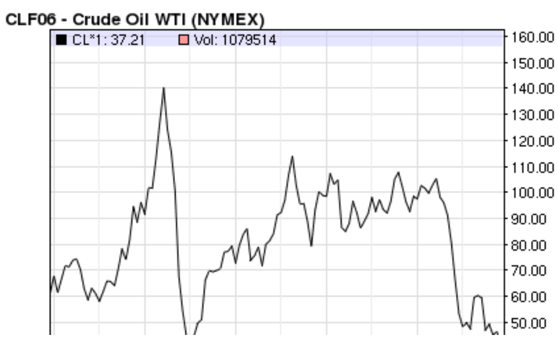
In the case of Amsterdam, Van Der Steen et al (2014) describe the role of dynamic 'policy entrepreneurs' who worked in a strategic manner, building narratives and networks to promote electric vehicles as a legitimate alternative. Practical incentives included establishing networks of charging poles, where initially users could park and charge their vehicles for free (until 2012). The success of these measures in Amsterdam sparked initiatives in other cities, such as Rotterdam, Utrecht and The Hague. Again, following a change in government, high-value support for EVs in Amsterdam was reduced in 2011, justified by a study which found that support for electric (private) passenger cars was not a cost-efficient way of reducing emissions, and better value for money could be achieved through redirecting support towards electric taxis and cleaner heavy duty vehicles (Boon and Bakker 2015).

An interesting issue here is that the cases of 'policy learning' described are contingent on analyses based on a different set of norms to those informing the creation of the policy (see Van Der Steen et al 2014). This raises broader questions regarding participation in policy-making and monitoring.

5.3 Drivers, Barriers and Incentives

5.3.1 Landscape (and Regime) Drivers

Major landscape drivers for the introduction of electric cars have been the need to improve air quality, and reduce CO_2 emissions. Others include industrial policy. For example, in the UK, Mazur et al (2015) note that major drivers include the 2050 emission reduction goals and the establishment of a local automotive industry that can produce electric vehicles. This contrasts with Germany, where, due to the strong incumbent automotive industry, the focus of resources has been in funding R&D in the development of vehicles, and in related areas such as lithium ion batteries, smart grids, and system integration. Similarly, in Norway, whilst reducing emissions is an important short-term goal, in the longer term it is hoped that EVs will contribute to stimulating research and development in new battery technologies (Holtsmark and Skonhoft 2014).



The public perception with which EVs are seen as a sustainable solution can also be a driver, and this to some extent relies on the level of renewable sources used to produce electricity. Holtsmark and Skonhoft (2014) observe that there is a "strong belief" in Norway that EVs are much more environmentally friendly, as almost 100% of Norwegian electricity is generated from renewable sources. Public perception can also be shaped by developments in the global car manufacturing, and the availability of more viable models on the market. Van Der Steen et al (2014) argue the importance of group dynamics here, where car manufacturers exert peer pressure to develop better models. In the case of Amsterdam, they describe a scenario where synergistic relationships were built between a range of actors. A further driver, which may also act as a barrier, is the cost of oil, as cheaper oil prices may make EVs more or less attractive, although industry research on this is inconclusive[33], given that sales are increasing and oil prices dropping. What is clearer is a relationship between cheaper oil prices and a decline in the use of biofuels as illustrated in Fig 4.3.

Fig 5.1 Oil prices since 2006 (Source: Nasdaq)

5.3.2 Barriers

Many of the barriers to EV diffusion might be more effectively described as absences: of standards, infrastructure, public confidence, or renewable sources of electricity. For example developments in charging infrastructure, including charging points and battery swapping capacity are essential (Dijk et al 2013). One major technical barrier is the issue of range discussed above, although more recent developments in technology are addressing this. EVs have typically tended to perform better over shorter distances on quieter roads, and have thus tended to be adopted out more in cities where they are used for short trips.

Van Der Steen et al (2014) cite the deeply rooted nature of patterns of mobility and planning based on the use of fossil fuels[34], for example mobility patterns based on settlement patterns where regular journeys exceed a certain distance, and the difficulty of installing charging points on residential streets. Patterns of mobility conducive to EV use are characterised by predictability and high-intensity of localised short trips (Turnheim et al 2014). Mobility patterns in areas such as rural Ireland (and also certain areas of Norway and Sweden) thus present a significant barrier to EV adoption, as distances travelled might often exceed the range of an EV. Problems have arisen through free parking being allowed in charging spots for EVS where non-charging EVs block charging points. In the Netherlands, introduction of free parking for EVs challenged the norms of the current parking regime, for example raising questions as to why EV users be privileged over other groups with needs such as parents of young children (Van Der Steen et al 2014).

A major barrier to the development of markets is cost, EVs tending to be more expensive depending on the model and electricity cost in the location, and thus only affordable through subsidies. In addition, uncertainties regarding performance and future costs raise issues of consumer trust and the resultant need for education through measures such as the provision of information and the opportunity to test drive cars (Turnheim et al 2014), such as those was provided in Norway. The sustainability of the electricity source used to power the vehicle (Sandy Thomas 2012) and the

[33] http://oilprice.com/Finance/investing-and-trading-reports/EV-Sales-Continue-Despite-Low-Oil-Prices.html

[34] See Box 3 for a discussion of the influence of related infrastructural factors, cultures and habits.

battery technology used are further questions which may affect adoption. Thus Gaines (2014) has advocated further research into technologies and regulations regarding lithium ion battery recycling, a much more complex process than that for conventional batteries.

Dijk et al (2013) note that the strong position of fossil fuels in the incumbent transport regime, illustrated for example by the large investment by car manufacturers into ICE vehicle development and increasing sales of cheaper ICE cars in emerging markets such as India and China still constitute major obstacles to EV adoption. However recent legislative changes in China to address pollution problems are beginning to have an influence on the number of EVs registered (Irish Times 15-12-2015).

5.3.3 Policy Incentives

There have been a wide range of government incentives to drive EV development, as discussed above, including funding for research, development and trials; infrastructural investment and market incentives. For example, initiatives in the UK include research programmes, a public procurement programme to enable the trial of low carbon vehicles in public fleets; a demonstrator programme for new low carbon vehicles; an investment programme to incentivise businesses to conduct research and produce demonstration vehicles in conjunction with academia, and a centre of excellence to focus on knowledge transfer and technology demonstration. To coordinate efforts in the UK, an Office for Low Emission Vehicles was established in 2009(Mazur et al 2015). In Germany, subsidies are given to promote tests of cars, vans and buses, and there are public procurement and demonstrator programmes. A number of national bodies including a national co-ordination platform have also been created to bring together and coordinate a wide range of key players to work on a relevant issues, including infrastructures, standards, training and recycling[35] (ibid). Boon and Bakker (2015) acknowledge the contribution of funding, regulating, and standardising the recharging infrastructure to Dutch successes with EVs. As discussed above, charging infrastructures were put in place by the electricity grid operators and local authorities in the Netherlands; in Norway, the government has funded infrastructural developments and in some cases free charging. However, there may difficulties in the implementation of certain incentives: Boon and Bakker (2015) note that in the Netherlands, organising collective procurement of EVs by public authorities and companies has proven impractical because of constraints with public procurement procedures (Boon and Bakker 2015).

A broad range of financial incentives have been used to build markets for electric vehicles. Market stimulants in the UK include plug-in vehicle grants; congestion charge exemptions in London; and the provision of exemptions from vehicle excise duty and company car tax. Unlike Germany, but in common with Ireland, there is also a vehicle purchase grant[36]. In Germany, EVs are exempt from vehicle tax for 10 years (Mazur et al 2015). In Norway, there are exemptions from toll road charges, and some ferry charges, reduced taxes, and free access to public parking (Figenbaum et al 2015).

Markets can also be driven by increasing comfort, convenience or improved perception based on hype, experience or education. In Norway, EVs can use bus lanes and avail of special parking spaces.

[35] German National Platform for Electric Mobility: 7 Workgroups: propulsion, batteries, charging and grid integrity, standards and certification, materials and recycling, training and education and framework creation. Network involves all big manufacturers, suppliers, utility providers, car clubs and associations, universities, research institutes and the public sector(Mazur et al 2015)

[36] https://www.gov.uk/plug-in-car-van-grants/overview (accessed 12-11-2015)

The culmination of a series of incentives, both financial and convenience-related, coupled with the emergence of new more comfortable and safer EVs on the market led to a huge rise in the use of EVs as second cars in Norway, an ICE car being retained by households for longer journeys (Figenbaum et al 2015, Holtsmark and Skonhoft 2014). Consumer confidence has also been built through the success of hybrid vehicles, notably the Toyota HEV Prius (Turnheim et al 2014), the interest of major car companies in EVs and the introduction of high end models such as the Tesla models discussed above, which extend the possibilities of using EVs. The founding of NEVA in Norway to promote the use of EVs through educating prospective customers, and enabling them to test drive models has greatly improved the perception of EVs (Figenbaum et al 2015). Table 5.1 summarises drivers, incentives and barriers.

5.3.4. Transition Dynamics

The above discussions indicate that clear and consistent policy measures appropriate to the level of development of EVs, together with market availability and other incentives such as cost have been helpful in their diffusion. One factor in Norway, which proved to be particularly useful, was an active coordinating body – NEVA who was very active in acting as an advocate for EVs, facilitating knowledge transfer, and offering test drives. A key point raised by a number of authors is the extent to which electric vehicles can actually be considered to be 'sustainable', or, as Augenstein puts it, "whether the current momentum of the electrification of the car may potentially contribute to a more sustainable transport *system*" (2015:102, emphasis added). To this end, she stresses the importance of distinguishing between a narrow conceptualisation of sustainable e-*mobility*, focused on reducing the environmental burden of vehicle *technology*, as opposed to a broader view, which would consider aspects such as urban liveability, equitable access to mobility and car-dependency[37].

Querying the transferability of EV promotion in Norway to other countries, Norway, Holtsmark and Skonhoft (2014) suggest that the growth in EV use and ownership may lead to more driving at the expense of public transport or cycling, and this may have significant carbon cost where electricity is not mostly produced from renewable sources. They note that in Norway, EVs have tended to be adopted as second household vehicles for use in daily commutes, with another ICE vehicle being retained for longer journeys, where previously only one car may have been owned (ibid). Increased road use may increase congestion problems, and the full environmental implications of the use of lithium ion battery technology in particular contexts need to be fully assessed. Mobility patterns in areas such as rural Ireland may present a significant barrier to EV adoption, as distances travelled might often exceed the range of an EV. In addition, trust in the performance of the technology, (such as in areas where roads are poor or subject to floods) and affordability may also be issues.

The above points underline the need for the context of use of a particular technology being considered and the sustainability implications of this. It is also very clear that the role of technologies needs to be considered in the context of a broader transformation in transport *systems* as part of a broader societal sustainability transition.

[37] As discussed in Box 2. above, many authors have advocated developments in inter-modal transport using of a variety of electric and non-electric vehicles such as bicycles e-bikes and e-cars in conjunction with public transport; a growth in different modes of practice such as car-sharing; and the adoption of new business models for car use based on sharing or leasing.

Landscape Influences •Electricity balancing needs •Car industry •Air pollution •Industrial policy		
TIS Function	**Drivers**	**Barriers**
Knowledge Development	Support for research and the production of prototypes, demonstrator projects (NO, UK, FR,UK,DE) Engineering schools in Germany, Denmark and Switzerland Research would stimulate R&D of new battery technologies(NO) Emergence of smart grids	Problems with Battery life Investments by auto manufacturers in the development of ICE vehicles
Knowledge Dissemination	NEVA (Norwegian Electric Vehicle Association) provides training, promotes EVs (NO). Transnova founded to support sustainable transport (NO). Office for Low Emission Vehicles, Centre of Excellence (UK) National Platform for Electric Mobility (DE)	Need for Consumer education (NL).
Entrepreneurial Activities	Public test program(NO) Public Procurement Programme (UK, DE), Demonstrator programs(UK,FR,NL,DE) Tesla Major car companies involved e.g. Nissan Leaf Funding to drive EV industry (UK) Subsidies to producers(NO)	Cheaper oil prices Change in mobility patterns Need to develop new business models (intermodality, car leasing)
Direction of Search	Climate protection policies and targets that included electric propulsion as a source of reduction of CO_2; Government support for EU policies	Dominant fossil-fuel transport regime Culture of driving
Market Formation	Progress in battery technology in consumer electronic sector. Introduction of a range of attractive, safer cars to the market by major car companies Less fuel cost- Developments in energy prices (e.g. increased oil prices) (NL, NO) Incentives for consumers- free parking, tax exemption from registration, road tax, income tax, free toll charges, vehicles license fee, use of bus lanes (SE, NO, NL, UK, DE- various) Use existing road infrastructures. Charging and plug standards(EU) Companies building charging infrastructures. Good public recharging infrastructure	Limitations to range before recharge Cost- More expensive to produce Need charging infrastructure and standards, including charging points and battery swapping. Different plug/charging standards Removal of subsidies(FR) Electricity grid operators not allowed to provide charging points after a certain point(NL) Preference for cheaper ICE cars in emerging markets (e.g. China)
Resource Mobilisation	Funding for research, infrastructural developments, development of	Inconsistencies in the provision of resources in the Netherlands-

	regulations and standards, subsidies, tax exemptions, free charging, etc. Economic recovery programmes (US, EU) favouring clean technologies Car manufacturers diversification strategy, including hybrid and pure EVs.	investor uncertainty. Organising collective procurement of EVs by public authorities - constraints with public procurement procedures(NL)
Legitimation	'Peak Oil' NEVA as advocacy body to promote electric car use (NO) No tailpipe emissions/reduce pollution. Advocated by electricity companies. Similar controls to existing vehicles. Belief that EVs are more environmentally friendly, as electricity generated from renewable sources (NO). Successful PHEV examples e.g. Toyota Prius FCVs and BEVs becoming an icon for zero-carbon vehicles	Sustainability of Batteries Renewability of electricity source Efficiency of private vehicles questioned[38] (NL) Cultural attachment to owning vehicles(NL) Need for Consumer education (NL)

Table 5.1: Summary and Examples of Barriers and Drivers for Electric Vehicles

[38] In Amsterdam, high-value support for EVs was reduced in 2011 after a study found that support for electric (private) passenger cars was not efficient, and better value for money could be achieved through redirecting support towards electric taxis and cleaner heavy duty vehicles

6. Discussion: Learning, Processes, and Indicators

The above case studies, based on syntheses of TIS and Transitions literature demonstrate the value of the use of different perspectives in analysing technologies in the context of a broader societal sustainability transition. The TIS approach is suited to providing a more detailed diagnosis of the current state of a technological *innovation system* through identifying barriers to innovation and in enabling the identification of targeted policy interventions, depending on the level of development of the technology and markets. However, this in itself does not provide the necessary contextual information necessary to assess the role that particular technologies could play in a broader sustainability transition. Transitions analyses provide broader and longer-term perspectives, in addition to detail on the role of learning processes and other niche dynamics. A combination of insights from both approaches, as discussed in Section 2, will provide the basis of a framework to analyse the Irish Case Studies in Paper 4. This is summarised in Table 6.1 below and detailed in Appendix A. However, it is how particular analyses can be *used* as an adjunct to different types of *learning process*, that will be key to their effectiveness in contributing to an overall societal transition. Drawing from the above cases and from the theoretical insights in Papers 1 and 2, this section focuses on possible categories and sites of learning for transition, and speculates on how these can be integrated into policy-making and innovation processes.

A key element in learning processes will be the identification of appropriate indicators and the (reflexive) design of frameworks for evaluation and reflection (such as those discussed above), based on both quantitative measures and qualitative analyses. The experience of EVs in the Netherlands, where there were changes in policy at national and local levels, following changes in government (and governing ideologies) raises a number of interesting issues regarding how policy issues are framed (Van der Steen et al 2015, Boon and Bakker 2015). Here, following a change in government, the responsibility for EVs shifted from the Department of Environment and Infrastructure to the Department of Economic affairs, resulting in a revision of EV policy measures (described as "policy-learning" by Boon and Bakker); in Amsterdam, incentives were removed as it was considered that there were more 'cost-effective' ways to reduce emissions (Van Der Steen et al 2014). These examples serve to illustrate that how problems and problem-solving are structured and framed can have a major impact on outcomes. For this reason it is important to underline the importance of building reflexivity, including clear statements of assumptions, into problem solving and structuring processes and to explicitly view issues from multiple perspectives. [39] The next three sections discuss potential classes of indicator (in a broad sense) that could be derived from and added to detailed analyses of technological innovation systems in Ireland (see Appendix A) to assess the potential of (possibly competing) technology niches to contribute to a society-wide sustainability transition.

6.1. Technology

Two dimensions of technological innovations are particularly relevant to consider: how developed or near to use a technology is, and how ultimately sustainable it might be in the longer term. These

[39] There is a need to:
1. Examine the extent of policy integration/co-ordination either present or required in the area being examined.
2. Examine the level of current stakeholder inclusion (who and how) in decision-making processes and the level of public participation in how developments have been framed at different stages.
3. Examine the extent to which reflexivity has been evident in policy approaches in those areas.

assessments (which may themselves be contested) can provide informational bases for further deliberation. It might also be important to assess a number of 'technological variants' (Markard et al 2008).

> **Technological Readiness Level (EU 2014, Innovation Seeds 2015)**: there is a need to assess the "technological readiness level" of a particular "niche technology", as different policy interventions might be appropriate for different levels of development, as the case of EVs in Norway clearly illustrates (see Innovation Seeds 2015[40] for a detailed description of levels). Expertise here could be indigenous or externally sourced and knowledge further developed through research, development and prototyping processes. The TIS method can also be used to provide indicators for the readiness level of a technology to be deployed within a particular geographical context. The extent to which lessons can be learned from other countries is relevant to consider here.

There is also a clear need to continually reflect upon and analyse the *sustainability* of particular technologies and their use, which may be uncertain and subject to contestation. Certain aspects will relate more directly to technological aspects (such as carbon emissions generated in the production process) and others to unintended side effects which may emerge, for example, as markets develop. The case of biofuels (as discussed in Box 1) has provided a strong example of where major policy alterations were required, through the emergence of (in some cases) unintended consequences. It also illustrates the danger of '**lock-in'** to a technology which proves to be less sustainable.

> **Sustainability**: These points raise the need for life-cycle assessments of options, which include full supply chain data. As discussed above, the need to address sustainability issues in the area of bioenergy are widely acknowledged. This is an interesting consideration to make at this point in the development trajectory of electric vehicles, as considerable uncertainties still exist regarding the sustainability of batteries, or the potential of increase in car ownership, at the expense of public transport or walking/cycling, especially where electricity is fossil-fuelled. Determining how such emerging evidence can be considered in decision-making processes on an on-going basis is important to consider.

6.2. Context of Use

In addition to factors primarily relating to aspects of technology, there are factors more directly concerned with where and how they are used. One point illustrated in the biogas case, is the need to evaluate the sustainability and appropriateness of a technology for a particular context of use. Here the benefits of on-going practical experimentation, incremental learning processes and knowledge-sharing networks were clearly illustrated in the Danish case. In this case also, the existence of strong farming co-operatives and strong interest in alternatives to fossil fuels in the Nordic Folke Center, where experimentation and knowledge dissemination could continue later eased adoption.

> **Co-ordinated Learning Networks:** This assesses the existence of strong learning networks, involving users, producers, researchers (and other interested members of civil society) etc. coordinated at a national level and linked to other international networks to enable knowledge to be effectively disseminated and shared (e.g. via regular fora, websites etc. at local, national and international levels). Examining the extent to which these exist provides an interesting indicator of the **learning capacity** within a particular niche.

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[40] See http://www.innovationseeds.eu/Virtual_Library/Knowledge/TLR_Scale.kl for a more detailed description of the TRL scale.

How a technology is used, and how its use is negotiated raises major issues of social acceptance in the development and innovation of low carbon technologies. One dimension of social acceptance of a technology is the acceptance of all *consequences* of the innovation including the ways in which it will change *social practices*[41] (Wolsink et al 2012, Shove and Walker 2010), including work practices, mobility practices and day to day habits. Problems may be ameliorated to a certain extent through participation by a wide group of stakeholders (including civil society) in relevant aspects of development processes from an early stage, as discussed above, where learning, envisioning and knowledge dissemination become central processes.

> **Social Acceptance – social practices**: An assessment of the extent to which a technology will change social (work, mobility etc.) practices and an assessment of how best potential users (or those whose social practices may be affected) are/could be involved in design and implementation processes. This provides an indication of reasons why certain technologies might not be adopted, and may indicate potential losers in innovation processes.

A further aspect of social acceptance discussed above regards the *settings* in which implementation will take place. Here issues of ownership and trust arise, and these are influenced by the level of stakeholder involvement (including meaningful deliberation) in planning and managing aspects of the design and implementation of the technology. As identified by Wolsink et al (2012), and discussed above, factors such as the emotional and cultural relationship between people and location play a highly significant part in degree of acceptance in addition to economic factors. Broader environmental factors also play a significant role. Here the extent of involvement of local community and other related groups is important to consider, as clearly outlined in the NESC 2014 study on wind energy in Ireland (NESC 2014 a, b).

> **Social Acceptance - spatial issues**: Extent of stakeholder involvement and participation in development and planning processes and how these could be achieved at different levels could be assessed here. The level of ownership in the process is also important to note.

6.3 Policy Learning

The biogas case, where the production of gas also contributed to solving problems with farm waste, illustrated the benefit of evaluating the use of a technology in a broader context. The Norwegian case, where the growth of EVs may have caused a reduction in the use of other, more sustainable forms of transport raises the need to consider EVs within broader mobility strategies. A broader view thus helps to identify emerging synergies, but also serves to ameliorate the dangers of blind spots and unintended consequences of policies at different levels and in different areas. It is particularly important to identify where dependencies might arise between areas, which may lead to less optimal solutions, for example in areas such as the production of energy from certain types of waste. This raises a need for the assessment of policy coherence and to examine how policymaking could be integrated both horizontally and vertically (see NESC 2015).

[41] This can be seen to work in ways in ways more or less desirable from either user or broader sustainability perspectives. For instance, in the case of Norwegian EVs above, where second car use increased, new social practices (and possibly dependencies) developed, which were arguably less desirable from a sustainability perspective, but maybe more comfortable from a user's perspective.

To this end, as discussed in Section 2, Weber and Rohracher (2012) have suggested 'new interfaces' between existing innovation policy arenas and other types of policies or actors and including formal and informal discursive spheres. These "hybrid forums" (one example being Dutch 'transition arenas' - see Paper 1 and Section 2) can be of different types and composition, and could act as coordination devices for sense-making and envisioning or as spaces for interaction, experimentation, monitoring and learning. A continuous monitoring and anticipation function (using assessment frameworks, enabling multiple perspectives, and future-oriented techniques such as scenario planning or backcasting), could be contribute to an evidence and resource base for legitimising policy interventions. These could also draw from existing data sources, and function as fora for information exchange round a particular issue; the inclusion and participation of a wider range of actors could ensure additional perspectives, and reflexivity in analysis.

> **Policy Coherence/Policy Integration Mechanisms:** The need for **policy integration**, to address potential incoherence, and the need for policy co-ordination between different sectors and different levels has been reviewed in depth by Mullalley and Dunphy (NESC 2015). Existing capacities for policy integration and co-ordination (at both design and implementation stages) would be interesting to assess.

As the cases above also illustrate, in many instances policy instruments were revised often due to ineffectiveness or unsustainability. Unintended side effects of the way in which policy measures might unfold leads to the need for policy learning, or more adaptive policymaking processes, requiring a degree of reflexivity. However, in some cases this needs to be balanced with the need to provide certainty for investors and/or communities if they are to be encouraged to engage in potentially risky projects. Certain side-effects can be avoided by involving appropriate stakeholders (including, for example, potentially affected communities) at design stages; however there is also a clear need for reflection and revision, particularly to avoid "lock-in" to ultimately less sustainable solutions which may note be immediately apparent, as experience with biofuels has clearly indicated. There is a paradox here: on one hand, many of the above cases illustrate how success has most often been achieved through sustained government commitment, as with Norway's commitment to BEVs and Sweden's to biofuels or Denmark's to biogas. Nordic countries (and Germany) provide examples of the benefit of strong and steady state intervention in contrast to Dutch or UK cases, where uncertainty, caused to some extent by volatile policy environments is frequently cited as a barrier to investors. A balance thus needs to be struck between flexibility and stability.

In this context, the need to examine the nature of the on-going relationship between policy-making and the research evidence base is important, including the adequacy of current research structures for forming an evidence base that can be used in policy making for climate transitions, and the mechanisms through which such evidence can be utilised in decision-making processes. A key element of reflexivity will be getting evidence of sustainability performance to policy makers more quickly than currently happens. For example, it took almost a decade for EU Renewable Fuels policy to change from when the first evidence on the sustainability performance/GHG emissions from 1G biofuels emerged.

> **Policy Learning /Reflexive Governance Mechanisms**: There is an argument to involve a broader range of stakeholders (including civil society) in policy-making processes who could

highlight potential issues before policies are enacted, and regularly evaluate policies for their effectiveness. Examining how decision-making is conducted, who is involved and whether and how reflection occurs might provide a useful assessment of where and how policy learning mechanisms could be put in place. The effectiveness of research structures used (or could be designed) to provide evidence bases which can be effectively employed in reflexive policymaking processes is also of interest here. The extent and level of participation in decision-making might also be assessed.

6.4 A Framework for Assessment

Table 6.1 summarises a framework using the TIS functions, adapting insights from the 'systemic instruments' (Wieczorek and Hekkert 2012), and transformational failures frameworks (Weber and Rohracher 2012), to explicitly address the some of the above concerns, and incorporate concepts from transitions analysis. This framework will be used to structure Irish Technology Case Studies, and also to inform a broader contextual analysis which we believe is essential when considering individual technologies. A set of questions is specified for each area, which will enable a mapping of the state of the innovation system for that technology. A more detailed version of this table is provided in Appendix A.

TIS Functional Areas	**Key Questions/Indicators**	**Possible Questions**
Knowledge Creation taken broadly to include the different types of knowledge to enable change	**How is knowledge created and learning structured?** **Level of development of technology (TRL), including extant problems**.	Who is involved in research and development, and what type of research are they conducting? To what extent are reflexive processes built into knowledge creation/or funding of this?
Entrepreneurial Experimentation (taken more broadly to include social entrepreneurs)	**How has the technology been demonstrated /implemented?**	What licensing issues exist? What infrastructural requirements exist? What are the relationships between entrepreneurs and communities/locations?
Knowledge Dissemination	**How is knowledge disseminated and how effective are mechanisms for dissemination?**	What national and global networks exist, and who are the main actors? What forums exist to share knowledge?? How is knowledge communicated to civil society actors?
Direction (Guidance) of Search	**Is there a clearly articulated vision (at whatever level is relevant) within which this technology fits?**	Who are the **main actors** involved in shaping visions and expectations? How are sustainability issues incorporated? How are uncertainties dealt with? What level of **policy co-ordination or integration** exists? To what extent are civil society involved in setting the search direction?
Creation of Legitimacy	**What are the major issues affecting the social acceptance of this technology?**	How is the technology dominantly perceived? Who are the main advocacy coalitions for and against this technology and what are their positions/concerns? What is the level of and nature of participation of affected communities in the development and implementation of the technology?
Resource Mobilisation	**What are the key financial, human, and physical resources which need to be in place or mobilized?**	Where will the money come from?
Market formation	**What are the markets for this technology?**	Who are the potential users? What are the costs/problems for users? What infrastructures/ distribution chains are required for product dissemination?

Table 6.1 Summary of draft assessment Matrix (see Appendix A for a full list)

7.Conclusion

The aim of this paper was to review TIS and Transitions studies literature in order to construct technological case studies and provide an evaluative framework which could be used to assess technologies in the Irish context. This is provided in Appendix A and summarised in Table 6.1. above. Case studies of technologies based on reviews of literature, analysing their development from TIS and transitions perspectives have been provided. How analyses could be conducted and used in the context of a broader transition process is discussed in Sections 2 and 6. Paper 4 will test and refine these tools through conducting Irish case studies, and will report the results of these.

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Appendix A : Evaluative Framework for Technology Cases

TIS Functional Areas	Key Question (possible metrics/indicators)	Possible Questions
Knowledge Creation (taken broadly to include the different types of knowledge to enable change)	**How is knowledge created and learning structured?** Identify • Actors and Networks • Research projects • Training Programmes • Institutions • Incentives • Papers • Reports • Patents **Level of development of technology (TRL), and sustainability issues (including extant problems)**. • Core Gaps in Knowledge and where they are being addressed. • Learning/review processes in place	Who is involved in research and development, and what type of research are they conducting? [e.g. is the focus on technical solutions, systemic innovation or broader sustainability?] How much has been invested in research and by whom? [Is there an indigenous capacity?] What have the research outputs been in terms of e.g. reports and papers published, patents registered (and where)? What are the key issues for this technology: technical gaps in knowledge, acceptance issues,sustainability issues? To what extent are reflexive processes built into knowledge creation/or funding of this? To what extent are civil society actors involved in knowledge creation?
Entrepreneurial Experimentation **(**taken more broadly to include government, to social or community entrepreneurs)	**How has the technology been demonstrated /implemented?** Number and types of entrepreneur Number and types of Demonstration project/ Experiment Main institutional barriers e.g. licensing issues, planning regulations Infrastructural problems Social issues.	What are the number and types of entrepreneurial actor? How well are they networked? How and where do they operate? What are their main costs? Which financial incentives exist? What level of risk are they taking? What licensing issues exist? What infrastructural requirements exist? What are their relationships between entrepreneurs and communities/locations?
Knowledge Dissemination	**How is knowledge disseminated and how effective is this?** Networks Conferences Fora Websites, social media Reports Training courses Public engagement	What national and global networks exist, and who are the main actors? What forums exist to share knowledge? How is emerging knowledge shared – what structures are in place to enable this? What reports, resource bases exist? What are the main blocks to knowledge dissemination? What level of training is needed and to what extent is it being provided? How is knowledge communicated to civil society actors?
Direction (Guidance) of Search	**Is there a clearly articulated vision (at whatever level is relevant) within which this technology fits?**	Who are the **main actors** involved in shaping visions and expectations? What are the expectations for this technology? What programs and policies are in existence to support the development and implementation

	What mechanisms (if any) are used for future envisioning? Vision Participation level Expectations	of this technology? How are sustainability issues incorporated? How are uncertainties dealt with? What level of **policy co-ordination or integration** exists? To what extent are civil society involved in setting the search direction?
Creation of Legitimacy	**What are the major issues affecting the social acceptance of this technology?** List of acceptance issues by actor. Advocacy coalitions Participation approaches and levels	How is the technology dominantly perceived by, and what are the key issues for: • energy regime actors • government actors • environmental actors • potential users • civil society e.g. communities in areas where implementation occurs ? Who are the main advocacy coalitions for and against this technology and what are their positions/concerns? What is the level of and nature of participation of affected communities in the development and implementation of the technology?
Resource Mobilisation	**What re the key financial, human, and physical resources which need to be in place or mobilized?** # grants, € allocated, timescales, perception of adequacy Availability of skilled labour No.of training courses Physical resources needed infrastructure support required. Carbon footprint of transportation? Sustainability?	**Financial** What financial resources exist to develop this technology, where do they originate and how are they allocated? Are these appropriate or adequate? **Human** What level of expertise is needed? What is the availability of skilled labour? Do sufficient training courses exist? **Physical Resources** What physical resources are required? Who provides them – how complex is the supply chain (which other regimes are involved)? Do they exist in the location or must they be transported? Do any issues arise concerning the sustainability of these resources?

Market formation	**What are the markets for this technology?** Existing markets Market size Market incentives Market barriers (e.g. cost including sunk costs, infrastructures, knowledge)	Who are the potential users? What are the costs/problems for users? What infrastructures/ distribution chains are required for product dissemination? How viable is the market? What is the current level of adoption? Are there institutional (e.g. government) incentives or barriers to market formation?

(broadly based on Weickzorek and Hekkert 2012, Weiczorek et al 2013, includes insights from Weber and Rohracher 2012, Smith and Raven 2012)